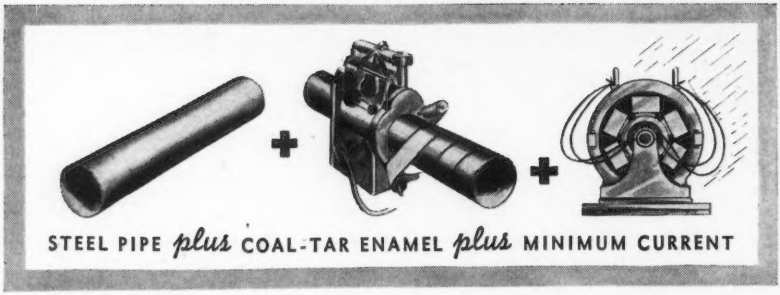
Corrosion



ECONOMICS OF CATHODIC PROTECTION

EXPERIENCE has demonstrated that Cathodic Protection can only be used economically, with protective coatings that provide long lasting insulation.

Such insulation is furnished by the use of Barrett Coal-tar Enamels. Their proved resistance to moisture absorption provides an efficient electrical insulation over long periods of time.

Stability of the electrical resistance of Barrett Enamels requires a minimum of electrical energy and equipment to make Cathodic Protection economical, now and in the future.

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ALLIED CHEMICAL & DYE CORPORATION
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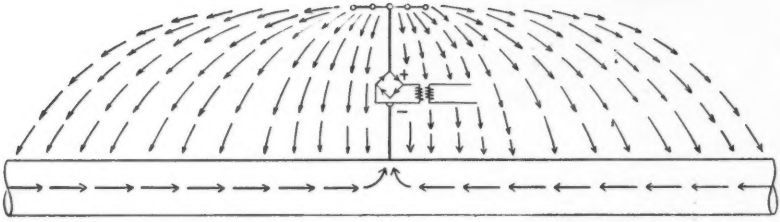
FIELD SERVICE—*The Barrett Pipeline Service Department and staff of Field Service men are equipped to provide both technical and on-the-job assistance in the use of Barrett Enamel.*

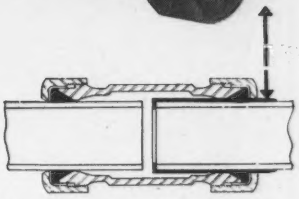
Barrett
COAL-TAR
ENAMEL



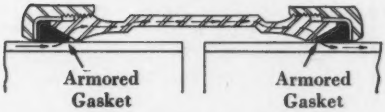
Protect your piping against CORROSION!

with Dresser Style 90 Fittings...

STOP CURRENT
at this Insulating Coupling →



CONDUCT CURRENT
through these Armored Gaskets →



Corrosion—wherever it strikes—is almost always of an electrochemical nature. In gas service lines, for example, leakage of electric current from homes may cause corrosion in mains. Protection is obtained (1) by insulating services at the main—or (2) by draining current from mains. Thus, according to piping design, either insulating or conducting fittings are required.

Dresser Insulating Couplings and Fittings (high resistance) and Dresser Couplings equipped with Armored Gaskets (low resistance) meet requirements of any electrolytic or cathodic protection system.

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—available with insulating gaskets or Armored Gaskets.

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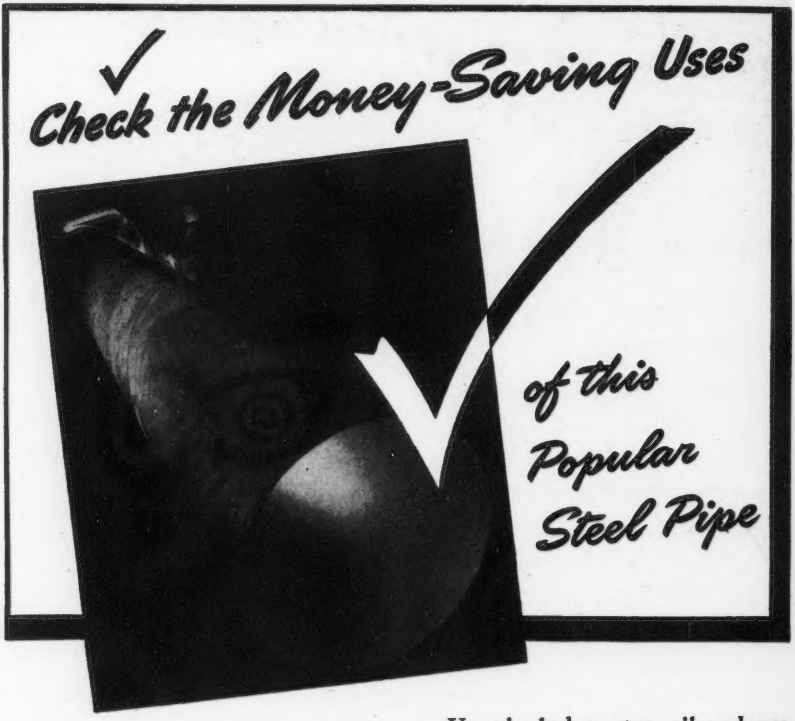

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For your next piping job ask for prices and shipping dates on ARMCO Spiral Welded Steel Pipe. Just address Armco Drainage & Metal Products, Inc., Welded Pipe Sales Div., 2561 Curtis Street, Middletown, Ohio.

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ARMCO

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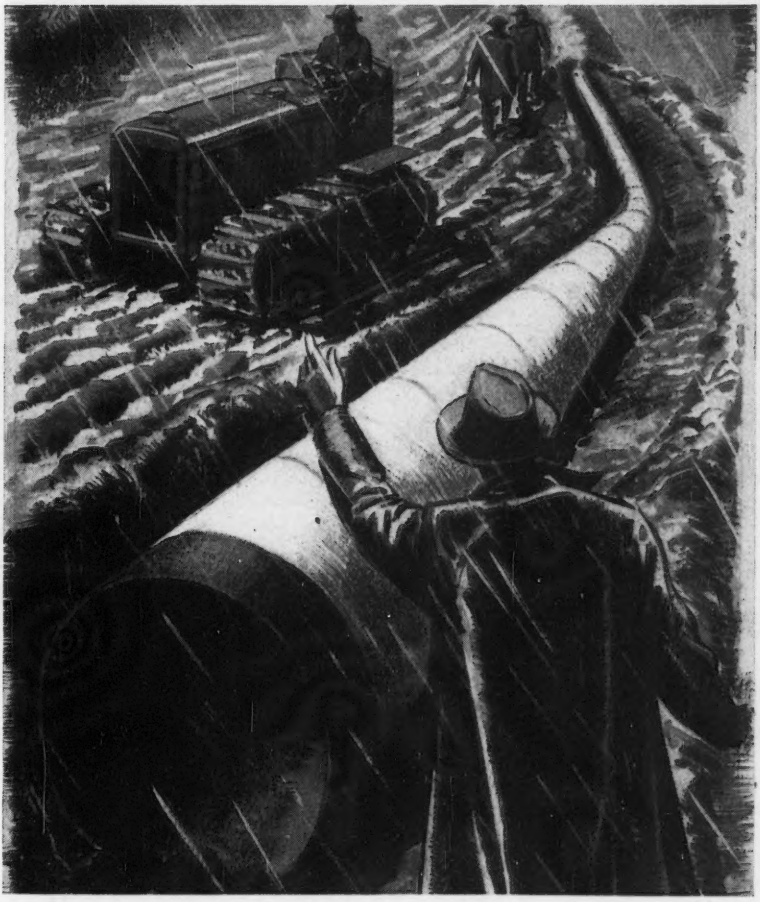

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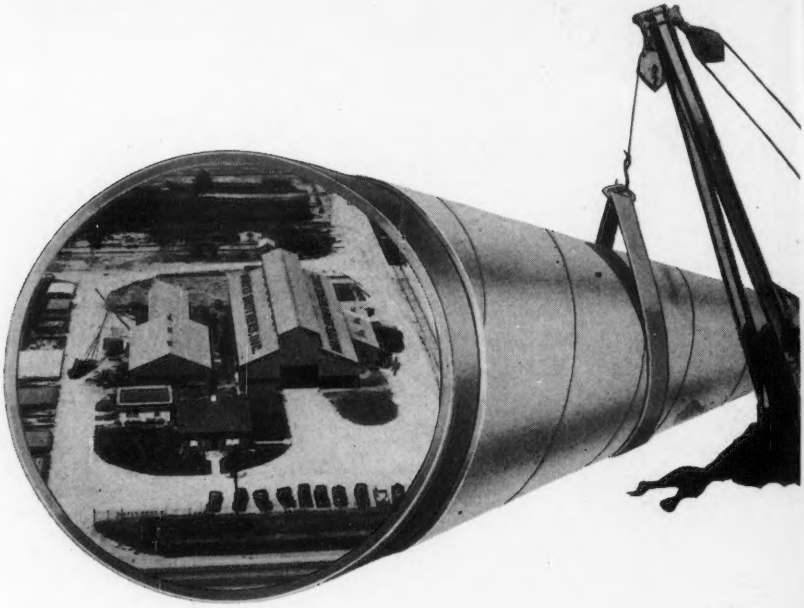

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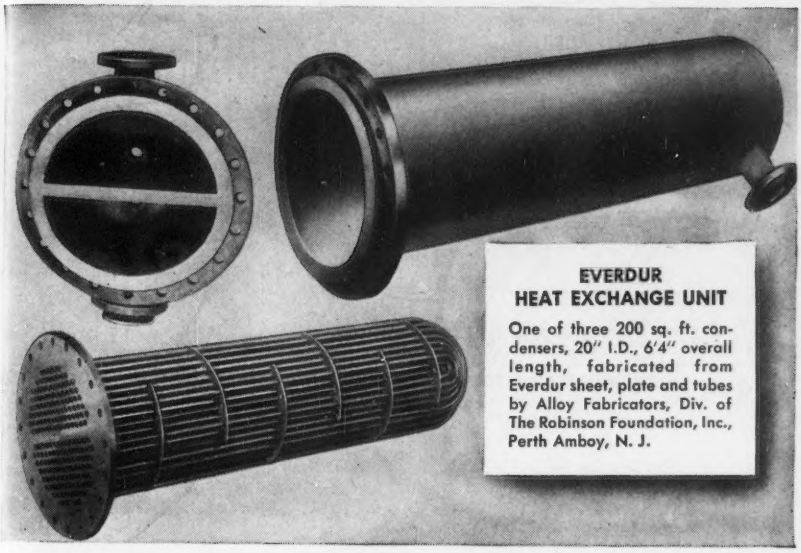

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One of three 200 sq. ft. condensers, 20" I.D., 6'4" overall length, fabricated from Everdur sheet, plate and tubes by Alloy Fabricators, Div. of The Robinson Foundation, Inc., Perth Amboy, N. J.

This two-pass heat exchange unit is a good example of thorough workmanship and sturdy, corrosion-resistant construction of Everdur*. Used for condensing hot vapors in the manufacture of synthetic rubber, it is one of three such units built by Alloy Fabricators, Div. of The Robinson Foundation, Inc., Perth Amboy, N. J.

The shell and removable head were formed from 3/16" thick Everdur sheet. The shell was carbon-arc welded with rods of Everdur 1010. Everdur plate 7/8" thick was used for the tube sheet, the tubes being 3/4" by .065" gage Everdur.

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For condenser tubes and other parts of heat exchange equipment subjected to heat and corrosion, Everdur Metal is but one of a number of Anaconda Copper-base Alloys which provide long, economical service under widely varying conditions. For detailed information, write for Publication B-2. *Reg. U. S. Pat. Off. 45123 A

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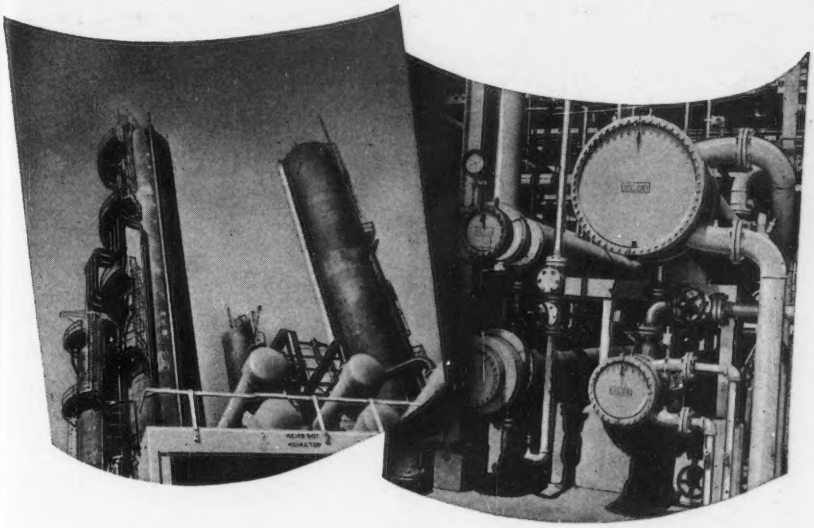

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American Locomotive

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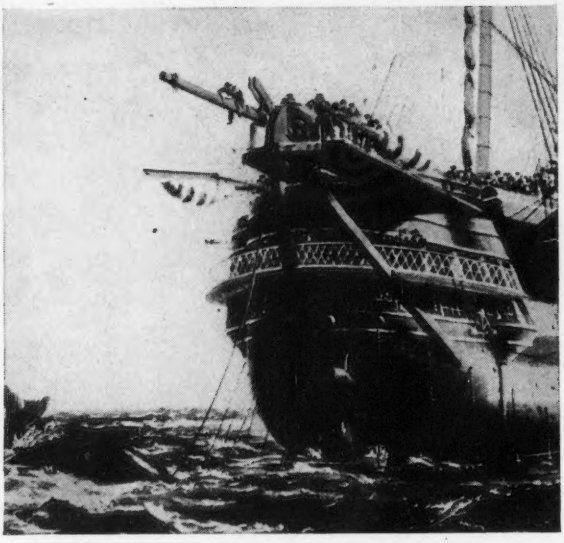

H.M.S. Agamemnon laying the first Atlantic cable.

Famous Facts

The first Atlantic cable was laid between Cape Breton, Nova Scotia, and Newfoundland. In 1857 the cable was completed to Ireland and the first messages sent between New York City and Europe the following year.

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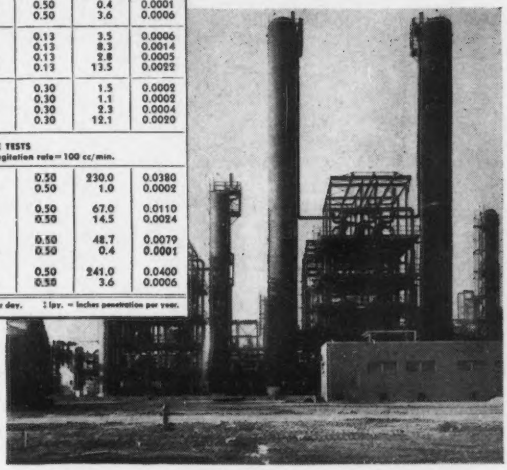
FOR RESISTANCE TO HF CORROSION IN ALKYLATION

MONEL CORROSION TESTS IN HYDROFLUORIC ACID

Material	Acid Conc. %	Temp. °F.	Agitator Gas	Time Days	Area* dm²	CORROSION RATES Mdd†	CORROSION RATES ipy‡
AIR-FREE TESTS—Nitrogen agitation rate = 100 cc/min.							
Monel (wrought) (approx. 69% Ni, 29% Cu)	25	86	Nitrogen	6	0.50	1.0	0.0002
	25	176	Nitrogen	6	0.50	14.5	0.0024
	50	86	Nitrogen	6	0.50	0.4	0.0001
	50	176	Nitrogen	6	0.50	3.6	0.0006
Monel (cast)	25	86	Nitrogen	6	0.13	3.5	0.0006
	25	176	Nitrogen	6	0.13	8.3	0.0014
	50	86	Nitrogen	6	0.13	2.8	0.0005
	50	176	Nitrogen	6	0.13	13.5	0.0022
"S" Monel (cast, non-galling)	25	86	Nitrogen	6	0.30	1.5	0.0002
	25	176	Nitrogen	6	0.30	1.1	0.0002
	50	86	Nitrogen	6	0.30	2.3	0.0004
	50	176	Nitrogen	6	0.30	12.1	0.0020
AIR-SATURATED VS. AIR-FREE TESTS Air agitation rate = 300 cc/min. . . Nitrogen agitation rate = 100 cc/min.							
Monel (wrought)	25	86	Air	1	0.50	230.0	0.0380
	25	86	Nitrogen	6	0.50	1.0	0.0002
	25	176	Air	1	0.50	67.0	0.0110
	25	176	Nitrogen	6	0.50	14.5	0.0024
	50	86	Air	1	0.50	48.7	0.0079
	50	86	Nitrogen	6	0.50	0.4	0.0001
	50	176	Air	1	0.50	241.0	0.0400
	50	176	Nitrogen	6	0.50	3.6	0.0006

* dm^2 = Square decimeter. † Mdd. = Milligrams per sq. decimeter per day. ‡ ipy. = Inches penetration per year.



Hydrofluoric alkylation unit at one of the world's largest and most modern refineries. It made possible a tremendous increase in production of 100-octane aviation superfuel.

Many metals, normally resistant to common forms of corrosion, are subject to severe damage by hydrofluoric acid.

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* * *

Over a period of years, the Corrosion Engineering Section of INCO's Development and Research Division has accumulated much valuable data on corrosion. We welcome the opportunity to apply these data to *your* problems or to work with your engineers on the problems facing them.

In addition, our Technical Staff stands ready to give help with welding or other fabrication questions which involve Monel, "S" Monel or other nickel alloys.

Practical information which most refinery men can put to immediate use, is contained in the *Summary of Corrosion Data in Hydrofluoric Acid;* in the article, *Corrosion in Petroleum Refineries;* and in Technical Bulletin T-10, *Corrosion Testing Methods.* Copies are yours for the asking. Write for them.

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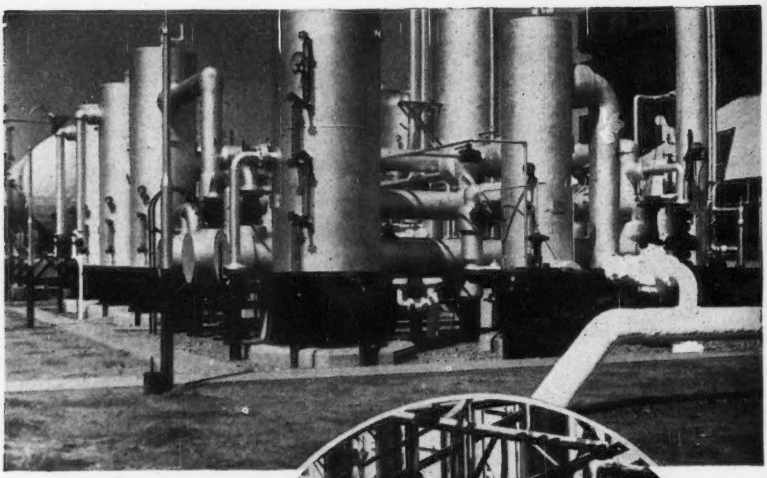

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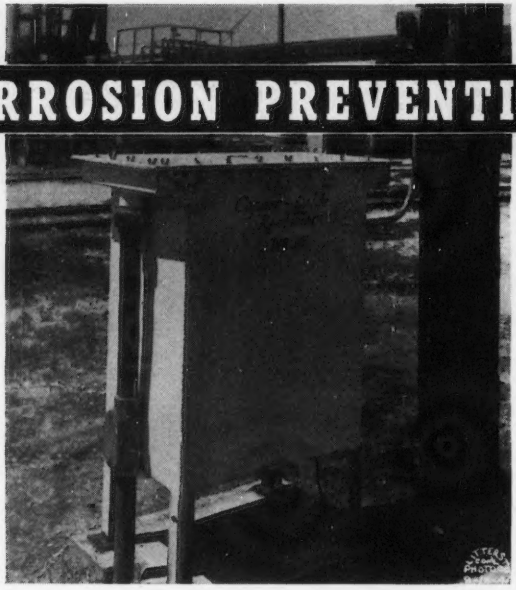

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(5) One spiral wrapping of desired wrapping material.
(6) One spiral wrapping of heavy kraft paper.

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INCLUDES
(1) Mechanical cleaning.
*(2) Mechanical priming with desired primer.
(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) Hot application of desired coating.
(7) One spiral wrapping of heavy kraft paper.

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Reilly Filled Pitch Enamel
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An Official Publication of the

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ELTON STERRETT, Executive Secretary

A quarterly publication—to provide in permanent record the papers prepared for the Association, at meetings, annual conventions and from editorial sources.

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New Horizons for N.A.C.E.

War—Rumors of Peace—Peace—Reconversion—Hurricane—Floods—we have not lacked for topics of conversation.

It behooves each of us to take stock and look to the future. As individuals we have the responsibility of contributing to the society in which we live to make a just and durable peace and to make it work. Professionally, we have new avenues of approach to our problems by virtue of release of wartime restrictions on men and materials. As members of the National Association of Corrosion Engineers, we have the framework for sharing ideas and developing and coördinating methods.

We are fortunate indeed to have completed our reorganization, and to have published in pamphlet form the Articles of Organization and By-Laws, and to have obtained the services of Mr. Elton Sterrett as Executive Secretary. He was formerly a member of the editorial staff of *The Oil Weekly* and is considered to be well qualified for the job which involves managing the general office of N.A.C.E. as well as serving as managing editor of its publications.

The Board of Directors, meeting in Kansas City, September 17th and 18th, will lay the basic plans for carrying out all projects, will appoint committees to distribute the work of N.A.C.E. to many shoulders and will make plans for a national meeting at the earliest possible date, and thus set the machinery in motion to carry out the spirit and the letter of the Articles of Organization. It will, now, be possible for N.A.C.E. to carry on its activities on a national scale and to make extensive and valuable contributions to the science of corrosion control.

A number of projects which have been postponed pending the adoption of the revised Articles of Organization and By-Laws are to be carried through as rapidly as possible. One of the projects is a membership drive for all classes of members. It is particularly important that a large proportion of the individual engineers, scientists and others working in any field of corrosion or corrosion control become associated with N.A.C.E. as Active Members. An opportunity will be offered to companies, firms or other organizations to participate in the work of N.A.C.E. by becoming Corporate or Associate Members as soon as incorporation of N.A.C.E. is complete.

It is the responsibility and privilege of the individual members of N.A.C.E. to carry out any program set-up. It is essential that local groups be formed and express both their group and individual opinions to the national organization so that the program and policy will represent the wishes of the members. It is the desires of the leaders that N.A.C.E. be national in geographical scope and complete in coverage of all fields of corrosion, that it will be accepted as the logical leader in activities relating to corrosion and that its publications and programs will be considered the logical media for presenting data and information on corrosion.

Corrosion
An Official Publication of the
NATIONAL ASSOCIATION OF
CORROSION ENGINEERS

Volume 1 SEPTEMBER, 1945 Number 3

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The Corrosion Resistant Characteristics of Some Condenser Tube Alloys

By A. W. Tracy
Assistant Metallurgist, The American Brass Company

COPPER alloys find extensive use in refineries and power plants in the form of tubes and sheets for condensers and heat exchangers, primarily because of their excellent corrosion resistance and their freedom from the formation of voluminous corrosion products even under corrosive conditions. The properties of some of the standard metals employed in heat exchangers and condensers are shown in Table I. The values in Table I should be considered as averages, and variations in properties, due to manufacturing variables, must be expected.

Figure 1—75 Diameters. Uniform dezincification of Admiralty on steam side of oil heater.

Types of Corrosion Occurring Under Refinery Conditions

Since the principal use of copper alloys in oil refineries is for tubes and sheets in heat exchangers and condensers, a large part of this discussion will be concerned with the several types of tube failure that may occur and steps to be taken to eliminate or minimize such failures. It is not entirely surprising that oil refineries should encounter all types of corrosion because cooling waters vary from polluted sea water to clean well water and highly aerated spray pond water to hard scale-forming water. On the vapor side tubes may be in contact with products from "sweet" crudes or may be

TABLE I

Properties of Non-Ferrous Condenser Tubes and Plates[1]

ALLOY	Copper Percent	Zinc Percent	Tin Percent	Arsenic Percent	Aluminum Percent	Nickel Percent	Tensile Strength Lbs./ Sq. In.	Yield Strength at 0.5% Elongation Under Load Lbs./ Sq. In.	Elongation in 2 Inch Percent	Thermal Conductivity B.t.u./ Sq. Ft./ In./°F. at 68° F.	Average Coefficient of Linear Thermal Expansion per °F. (77-572°F.)
TUBES											
Admiralty Alloy, 442	70.0	29.00	1.00	....	....	....	50,000	20,000	40	768	0.0000112
Arsenical Admiralty, 439	70.00	28.95	1.00	0.05	....	....	50,000	20,000	40	768	0.0000112
Aluminum Brass	76.00	21.95	....	0.05	2.00	....	50,000	20,000	40	696	0.0000108
Cupro-nickel:											
80–20, Alloy 712	80.00	....	....	....	....	20.00	50,000	20,000	40	252	0.0000091
70–30, Alloy 701	70.00	....	....	....	....	30.00	50,000	20,000	40	204	0.0000090
Red Brass, 24	85.00	15.00	....	....	....	....	42,000	15,000	40	1104	0.0000104
5 percent Aluminum Bronze, 901	95.00	....	....	....	5.00	....	60,000	30,000	60	552	0.0000099
Arsenical Copper, 108:					**Phosphorus**						
Light Drawn	99.68	....	....	0.30	0.02		40,000	35,000	20	1344	0.0000098
Hard Drawn	99.68	....	....	0.30	0.02		45,000	40,000	7	1344	0.0000098
Deoxidized Copper, 939:											
Light Drawn	99.9+	....	....	....	0.02		40,000	35,000	20	2364	0.0000098
Hard Drawn	99.9+	....	....	....	0.02		45,000	40,000	7	2364	0.0000098
PLATES											
Muntz Metal, 274	60.00	39.50	....	....	....	**Lead** 0.50	50,000	20,000	35	....	0.0000116
Naval Brass, 452	60.00	39.25	0.75	....	....	....	56,000	25,000	35	....	0.0000117
Admiralty Alloy, 442	70.00	29.00	1.00	....	....	....	45,000	15,000	40	....	0.0000112
Aluminum Brass, 927	76.00	21.95	....	0.05	2.00	....	45,000	25,000	40	....	0.0000108
70–30 Cupro-nickel, 701	70.00	....	....	....	....	30.00	54,000	26,000	40	....	0.0000090
Deoxidized Copper, 939	99.9+	....	....	....	**Phosphorus** 0.02		35,000	16,000	35	....	0.0000098

in contact with high sulphur constituents from "sour" crudes.

Dezincification Type of Corrosion

A casual examination of a dezincified tube would give the impression that zinc was leached from the alloy leaving residual copper but actually in this type of corrosion the brass dissolves as an alloy (2). That is, all constituents are attacked, but the copper from the corrosion product is replated on the brass with the consequent formation of a galvanic cell in which the copper is the cathode and the brass is the anode. Low water velocities and high temperatures are conducive to dezincification corrosion.

In acid waters, dezincification occurs rather uniformly over the whole surface of the metal. General dezincification on the steam side of a non-inhibited Admiralty oil-heater tube is shown at 75 diameters in Figure 1. In alkaline waters, localized or so-called "plug" type dezincification occurs. This type of dezincification is usually characterized by a nodule of dirty white corrosion products under which there will be found a pit filled, or partially filled, with a plug or redeposited copper.

Figure 2, at 10 diameters, shows a cross section of a plain Admiralty tube corroded from the outside or water side by "plug" type dezincification. This tube was in an inland refinery. The "plug" of redeposited copper is porous and having no strength may easily be forced out of the cavity.

Brasses containing more than 15 percent zinc are more likely to dezincify than those containing less zinc and the tendency to dezincify increases as the zinc content of the brass increases. Dezincification of brasses can be decreased or inhibited by the addition of small amounts of other elements to the alloy. The function of the one percent tin in Admiralty is to decrease dezincification attack and plain Admiralty condenser tubes do quite well for

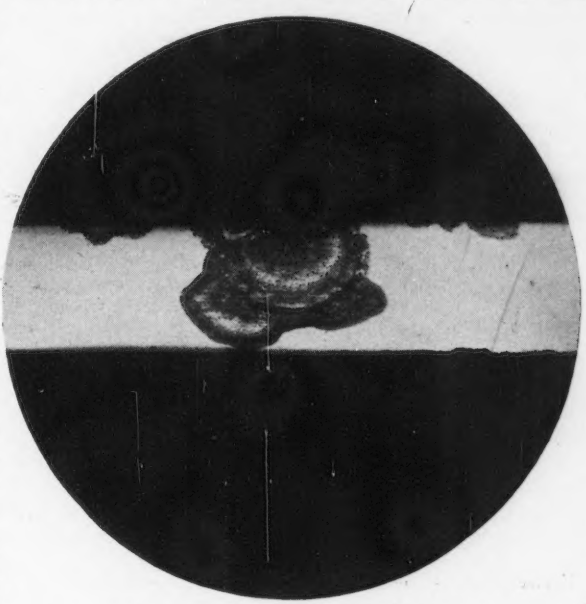

Figure 2—10 Diameters. "Plug type" dezincification of Admiralty from condenser in inland refinery.

marine condensers where and when temperatures are low and the cooling water fairly clean, but this alloy does not always satisfactorily resist corrosion by dezincification from polluted waters often found in refineries. It has been found that the addition of a trace of arsenic, antimony or phosphorus to Admiralty makes the alloy definitely more resistant to dezincification. The effect of the arsenic is probably to change the potential at the surface of the metal, preventing the redeposition of copper and to prevent the formation of the copper-brass galvanic cell.

Figure 3—6 Diameters. Impingement or erosion-corrosion of Admiralty tube from condenser in tanker.

Previous to the introduction of inhibited Admiralty condenser tubes, red brass (85 percent copper, 15 percent zinc) tubes were often selected because of their resistance to dezincification. However, the high copper content makes red brass less resistant than Admiralty to suphide attack.

Impingement Corrosion

Impingement corrosion is the attack of a metal by turbulently flowing corrosive water containing air bubbles (3). Air bubbles of a size which permits them to deform under pressure will tend to remove protective film from a surface on which they impinge. Air bubbles may be introduced into the water system around packing glands on pumps or may be formed while the cooling water is flowing through the condenser tubes in condensers set high above the ground. Such condensers may have a long leg on the exit side producing a high enough vacuum to draw dissolved air out of the water in the form of bubbles. This type of corrosion is more prevalent in refineries using sea water for cooling than in those using inland waters.

Corrosion-erosion is similar to impingement corrosion but is not quite so rapid because air bubbles are not involved. It is caused by highly turbulent flow of cooling water removing metal ions from a corrod-

ing surface so fast that a protective film cannot build up. Debris, such as shells or iron rust scales, partially clogging a tube will set up turbulent flow and cause rapid corrosion-erosion. Neither impingement corrosion nor corrosion-erosion requires the presence of an abrasive material such as silt or sand in the water. The presence of an abrasive will accelerate these types of corroding by removing corrosion products from the area under attack and perhaps even abrading away solid metal.

Pits caused by impingement or erosion-corrosion are free from corrosion products and are elongated and under-cut on the down-stream end. The pits are often horseshoe shaped where some deposited particle has interfered with uniform flow. The "toe of the horseshoe" always faces up stream. An analogy has been drawn to the effect that they give the appearance of the footprints made by a horse walking up stream. Figure 3 shows the surface of an Admiralty tube with characteristic horseshoe shaped pits on the water side. The tube was in the condenser of a tanker.

Admiralty is definitely better than red brass for resistance to impingement or corrosion-erosion. The addition of dezincification inhibitors—arsenic, antimony or phosphorus—has very little effect in these types of corrosion. There is some indication that arsenic helps form a layer of corrosion products that is more resistant to impingement in sea water than is the case with the alloy containing no arsenic.

Impingement corrosion may be avoided or at least kept to a minimum by preventing the entrance or formation of air bubbles. This type of corrosion and corrosion-erosion may also be minimized by keeping tubes free from debris which would set up turbulent or non-uniform flow.

As already suggested, resistance to impingement corrosion or corrosion-erosion depends on the type of protective film which forms on a metal during use. The rating in sea water for some of the standard condenser tube alloys for resistance to these types of corrosion would be:

Copper—poor
Admiralty (plain)
Arsenical Admiralty
Aluminum brass
30% Cupro-nickel—best.

The addition of ½ percent of iron to 30 percent cupro-nickel markedly increases the resistance of this alloy to impingement corrosion (4) (5).

Stress Corrosion

Stress-corrosion cracking of condenser tubes is not a common cause of tube failures in refineries, but when it does occur, tube life may be extremely short. The best knowledge to date indicates that the stress-corrosion cracking of copper alloys requires the simultaneous action of an atmosphere containing moisture, oxygen and ammonia and a stress on the metal. Tubes having stresses residual from cold drawing will usually crack longitudinally. Such failures are rare because it is general practice to give condenser tubes a light recrystallizing anneal to relieve residual stresses. Longitudinal stresses may be set up while tubes are being rolled into a bundle or may be due to large temperature gradients in a bundle at high tem-

peratures. Tubes with a longitudinal stress will crack transversely. Stress-corrosion cracking is usually characterized by intergranular attack, possibly due to the greater vulnerability of the grain boundaries either from segregation of minute impurities or due to atomic distortions. However, when stresses are very high, cracks have been known to proceed across the grain rather than to follow grain boundaries. An example of intergranular corrosion in an Admiralty condenser tube from an oil cooler is shown in Figure 4 at 75 diameters. Another stress-corrosion cracked Admiralty tube is shown in Figure 5 at 75 diameters. The crack here is mostly transgranular, possibly because stresses were very high.

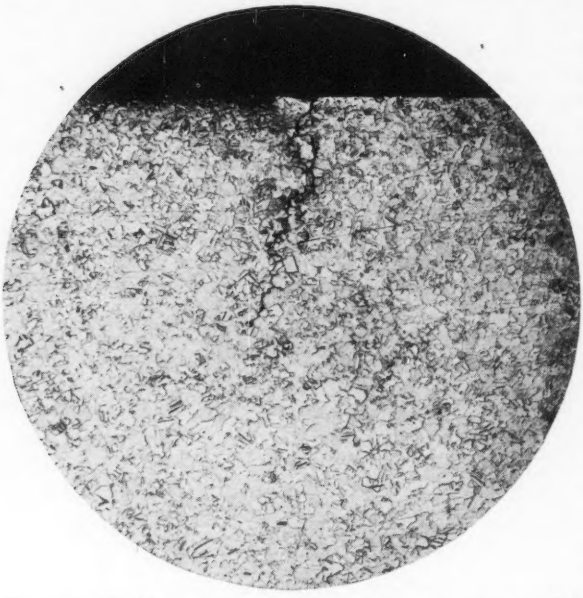

Figure 4—75 Diameters. Intergranular stress-corrosion cracked Admiralty tube in oil cooler.

The tendency of brasses to stress-corrosion crack increases with zinc content. Red brass is more resistant to this type of attack than Admiralty, and cupro-nickels are practically immune to this type of corrosion. Laboratory tests and field experience have indicated that the dezincification inhibitors — arsenic, antimony and phosphorus — have no effect on the resistance of Admiralty alloy to stress-corrosion cracking in at atmosphere containing ammonia.

The stress-corrosion cracking of Admiralty condenser tubes is not common even where fairly large amounts of ammonia are present in the overhead vapors, probably because the concentration of oxygen in the vapors is low. Still, the ammonia content in refinery vapors should be kept as low as posible and yet give corrosion protection to the iron parts of the equipment. The ammonia content should be so controlled that the pH of condensed water vapors is not over 9 and preferably it should not be over pH 8. Higher amounts of ammonia may not cause stress-corrosion cracking but may cause rapid thinning of the tubes.

Caustic soda or soda ash may be controlled at a higher concentration

than ammonia but it does not appear feasible to allow the pH of condensate containing caustics to be higher than 10. Cases are known where a combination of ammonia and soda ash or caustic soda in the overhead vapor lines caused rapid corrosion and cracking of Admiralty tubes. It was concluded that the soda ash or caustic soda had acted to keep more of the ammonia in the free states and there was also the thought that the soda ash or caustic soda had formed a semi-protective film on the Admiralty which helped to concentrate corrosive attack at grain boundaries.

Where large quantities of ammonia are present from decomposition of nitrogenous compounds during processing or by addition to prevent corrosion of iron, the introduction of water into the vapor will help keep the concentration of ammonia low and will also reduce the tendency for the bundle to become choked up with ammonium chloride or other salts.

Fatigue Failures

Although not a common problem in oil refineries, condenser tubes may fatigue crack if stresses set up by vibration are high enough to exceed the fatigue limit of the metal. Fatigue cracks always cut across grains and never follow grain boundaries. Work hardening of the metal adjacent to the crack may sometimes be observed. The outside surface of a tube which has failed by fatigue will often be in a battered condition where it passes through baffle plates. The best cure for fatigue failure is to find the cause of vibration and eliminate it, rather than to consider replacing with another alloy. Figure 6 at 75 diameters shows the start of a fatigue crack in an Admiralty condenser tube which failed after six months service in a butadiene plant.

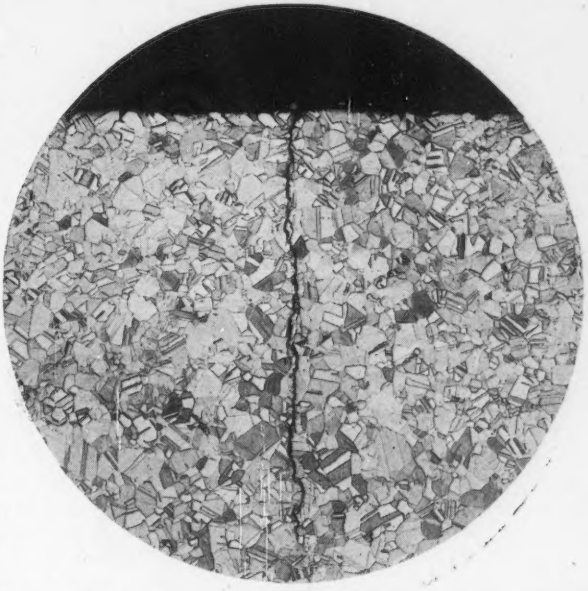

Figure 5—75 Diameters. Transcrystalline stress-corrosion cracking of Admiralty tube from heat exchanger in natural gas plant

Condenser Tube Metals

Some of the corrosion resistant

properties of non-ferrous condenser and heat exchanger tubes have already been mentioned, but it seems worth while to summarize the general properties of each.

Deoxidized and Arsenical Coppers—These metals do not find extensive use in oil refinery exchangers and condensers, primarily because of their low resistance to sulphide corrosion. Further, they do not offer satisfactory resistance to corrosion by rapidly flowing sea water.

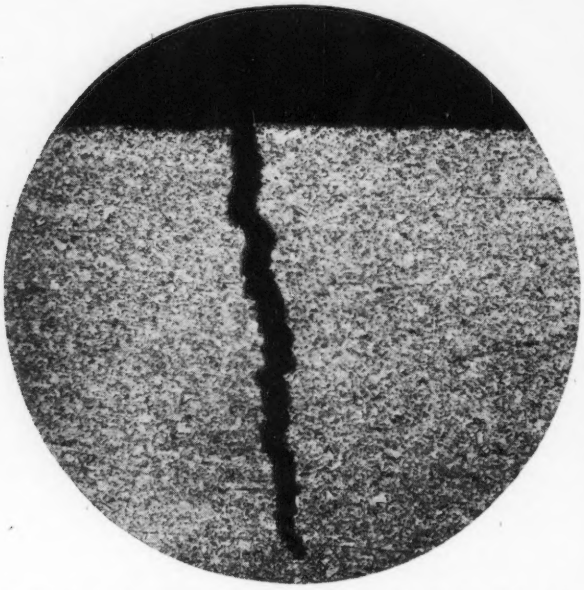

Figure 6—75 Diameters. Fatigue crack in Admiralty tube from condenser in butadiene plant.

Red Brass—Red brass has been employed for condenser tubes in refineries particularly under conditions where the older type of Admiralty dezincified. Red brass is definitely more resistant than copper to corrosion by sulphides and brackish waters. This alloy also offers good resistance to stress-corrosion cracking.

Admiralty—This alloy has been the standard non-ferrous condenser tube metal in the oil refinery industry for many years. It offers good resistance to sulphide and ammonia corrosion on the vapor side and is resistant to fresh, brackish and saline waters on the water side. The alloy has the property of building a good adherent, protective film of corrosion products making it resistant to corrosion under adverse water conditions. The value of Admiralty for refinery equipment has been markedly improved by the addition of small fractional percentages of either arsenic, antimony or phosphorus, which effectively inhibit dezincification by either acid or alkaline waters. Admiralty tubes find their greatest use in bundles where the temperatures of the entering vapors are not above 350 to 400° F.

Aluminum Brass—This alloy has not had extended trials in oil refineries. What information there is indicates that the alloy would offer about the same resistance as Admiralty from corrosion on the vapor side. Experience in power plants

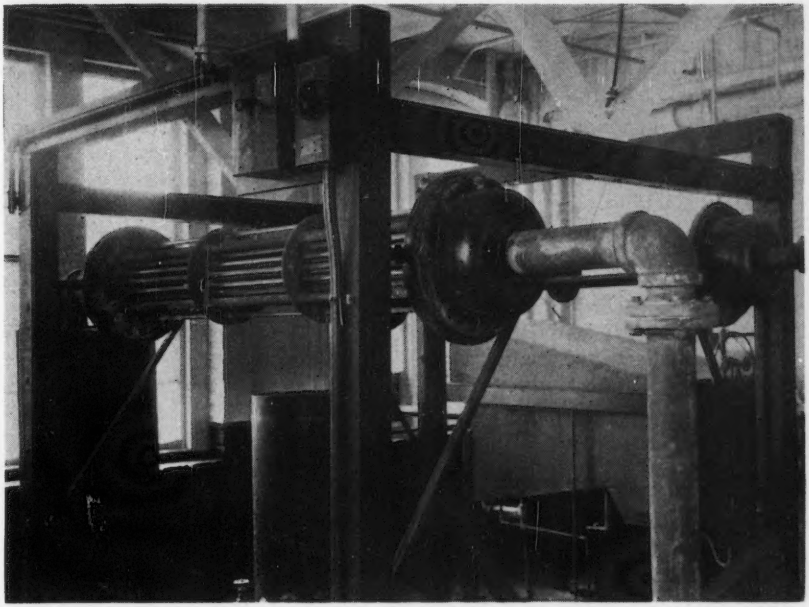

Figure 7—Experimental condenser for investigating corrosion resistance of tubes to water-side conditions.

and on board ship shows aluminum brass to offer better resistance to impingement corrosion by highly aerated clear or polluted sea water than has been offered by Admiralty. Refineries using sea water for cooling should obtain better service from aluminum brass tubes than from Admiralty tubes.

Cupro-nickels—Cupro-nickel (70 percent copper, 30 percent nickel) condenser tubes have advantageously replaced Admiralty in bundles where temperatures were above 400° F. and saline water was the cooling medium. Tube life for the 70-30 cupro-nickel has been three to four times that of Admiralty. This better service from cupro-nickel is the result of several desirable characteristics of the alloy. It retains a larger proportion of its tensile strength at high temperatures than does Admiralty and at the same time is definitely more resistant to corrosion by ammonia or caustic soda and practically immune to stress-corrosion cracking. The alloy is highly resistant to corrosion by all kinds of cooling waters. It has recently been found that the addition of ½ percent of iron to the 70:30 cupro-nickel adds further resistance to pitting and impingement corrosion by sea water.

Laboratory tests have indicated that 10 percent cupro-nickel containing ¾ percent iron is highly resistant to salt water corrosion (5). No data on its resistance to corrosion

from the vapor side in oil refineries are yet available.

Aluminum Bronze — The possible value of 5 percent aluminum bronze in refineries has not been investigated. This alloy has good strength properties and is resistant to stress-corrosion cracking. It is not as resistant as Admiralty to sulphide corrosion. Its resistance to sea water has been variable and may depend on the type of corrosion products formed during the initial exposure.

The alloys discussed are the result of development and testing carried on over a long period of years by many investigators. Research is still being done to discover better alloys for condenser tubes. Figure 7 shows an experimental condenser used in the Corrosion Research Laboratory of The American Brass Company to study corrosion factors affecting the water side of condenser tubes. However, no laboratory test will determine how a metal will stand up in a refinery condenser and the willingness with which progressive refinery engineers have coöperated in making plant tests has benefited both the refineries and the tube manufacturers.

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Due to the changes in committees, chairmen and other officials occasioned by the reorganization of the N. A. C. E. when the new Articles of Organization and By-Laws went into effect, there was neither time nor opportunity to pass on to the Editorial Committee, as originally constituted, the papers submitted for presentation in this number of CORROSION.

On page 160 are reprinted the References which should have appeared following the article "Analysis of Data in Cathodic Protection of an Open Condenser Box," by J. J. Stadtherr, but which, through an error in make-up, were printed as though with another article. They are here reproduced to correct the error, and to permit the clipping of the table of references for filing with the correct article without affecting he usability of material adjacent to it in the June number of CORROSION.

Light Metals for the Cathodic Protection of Steel Structures

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CATHODIC protection can be achieved by either one of two main methods; that is, by using current supplied from some external source, as a motor-driven generator, or by means of galvanic action resulting from contact of an anodic metal with the structure to be protected. In this paper, attention will be directed mainly to the second method of cathodic protection.

When a dissimilar metal or alloy is used to supply current to a steel structure, the first requirement is that the dissimilar metal or alloy must be definitely anodic to steel. The solution potentials of metals or alloys depend, to a considerable extent, on the medium in which they are exposed. However, a reasonable means of comparing the inherent reactivity of different metals is based on measuring the solution potential of each metal in a solution which is unit activity in the ions of that particular metal. Generally, these potentials are measured against a normal hydrogen electrode. A list of such potentials in decreasing order of activity is called the Electromotive Series.

In pipe-line work, generally the saturated copper sulfate electrode is used as a reference electrode. The potentials against this half cell are very nearly the same as those against a tenth normal calomel half cell. This tenth normal calomel half cell is often used in laboratory work because of its low temperature coefficient.

TABLE I

Reversible Potentials of Metals

(From Electromotive Force Series Referred to a 0.1N Calomel Cell Instead of a Normal Hydrogen Electrode.)

METAL	Potential, Volts	Difference in Potential Compared to Iron, Volts
Magnesium...	—2.68	1.90
Aluminum....	—2.01	1.23
Zinc.....	—1.10	0.32
Iron.....	—0.78	....

In Table I, the solution potentials of several metals which offer promise for use in the cathodic protection of steel structures are given. The values in this table are the same as in the customary Electromotive Force Series, except that they have been referred to a 0.1N calomel half cell instead of to the normal hydrogen electrode.

Now, while the potentials given in Table I are not always obtained in specific media, such as natural waters or moist soils, these values do indicate the inherent or potential behavior of the various metals. Thus, of the various metals listed in Table I, magnesium would be expected to develop the most anodic potential and iron the least anodic potential.

Any of the three metals having

potentials above iron offer promise of protecting iron in some specific environment.

Electrochemical Equivalents

While an anodic potential with respect to iron is of first importance in obtaining cathodic protection, current must also be supplied to the iron (or steel) structure. Current can flow only if some reaction, generally solution of the protective electrode, occurs at the anode. If metal from the anodic material is all used in supplying useful current to the steel, there is a definite relationship between the quantity of current supplied and the amount of anodic metal dissolved. This is known as the electrochemical equivalent of the metal. For all metals this can be calculated from the atomic weight of the metal divided by the valence at which the metal dissolves. Table II lists the electrochemical equivalents of several metals.

TABLE II

Electrochemical Equivalents of Several Metals

METAL	Weight of Metal Consumed per 26.8 Ampere Hours of Current Passed, Grams	Ampere Hours per Pound of Metal
Magnesium	12.2	997
Aluminum	9.0	1352
Zinc	32.7	372

From Table II it can be seen that, of the three metals listed, at *100 percent current efficiency* the smallest weight of aluminum is consumed per unit quantity of current passed (1). The weight of aluminum required is only 27.5 percent of that of zinc and 73.7 percent of that of magnesium, assuming all of the metal is used up supplying useful current.

Thus, if the data of both Table I and Table II are considered, magnesium is advantageous in that *theoretically* it should give the greatest potential against iron while aluminum is advantageous in that *theoretically* it should supply the greatest quantity of current per pound of metal.

Measurements Made Under Laboratory Conditions

It was emphasized in the preceding sections that the values given in Tables I and II were theoretical values obtained under reversible or ideal conditions. It is interesting to compare values of solution potential and current efficiency for the various metals under test conditions. A series of tests was therefore made under laboratory conditions to compare the solution potentials of the

TABLE III

Solution Potentials of Several Metals in Various Solutions

(All 1 molar in concentration unless noted. From Electromotive Force Series referred to a 0.1N Calomel Cell instead of a normal hydrogen electrode.)

METAL	Sodium Chloride	Sodium Sulfate	Sodium Chromate	Hydrochloric Acid	Nitric Acid	Sodium Hydroxide	Ammonium Hydroxide	Calcium Hydroxide (Saturated)	Barium Hydroxide (Saturated)
Magnesium	—1.72	—1.75	—0.96	—1.68	—1.49	—1.47	—1.43	—0.95	—0.88
Aluminum	—0.86	—0.50	—0.71	—0.80	—0.49	—1.50	—0.80	—1.54	—1.53
Zinc	—1.15	—1.19	—0.67	—1.14	—1.06	—1.51	—1.50	—1.40	—1.49
Iron	—0.72	—0.76	—0.16	—0.66	—0.58	—0.22	—0.18	—0.30	—0.25

various metals. The results are given in Table III.

It will be noted from the data in Table III that in neutral or acid solutions the potential of aluminum is generally lower than that of either zinc or magnesium. However, in the alkaline solutions (other than ammonium hydroxide), the potential of aluminum is as high as or higher than any of the other metals listed.

TABLE IV

Solution Potentials of Aluminum-Zinc Alloys in Various Solutions

(All 1 molar in concentration unless noted. From Electromotive Force Series referred to a 0.1N Calomel Cell instead of a normal hydrogen electrode.)

METAL	Sodium Chloride	Sodium Sulfate (Saturated)	Hydrochloric Acid	Sodium Hydroxide	Sodium Carbonate	Trisodium Phosphate	Calcium Hydroxide (Saturated)	Calcium Carbonate (Saturated)	Calcium Sulfate (Saturated)
Aluminum (2S)	—0.85	—0.50	—0.88	—1.47	—1.35	—1.32	—1.54	—1.04	—0.77
Aluminum with 1% Zinc (72S)..	—0.96	—0.76	—1.02	—1.56	—1.54	—1.53	—1.57	—0.99	—0.70
Aluminum with 5% Zinc.....	—1.04	—0.82	—1.08	—1.58	—1.50	—1.54	—1.57	—1.05	—0.82
Aluminum with 10% Zinc.....	—1.05	—0.66	—1.12	—1.58	—1.52	—1.53	—1.58	—0.98	—0.84
Aluminum with 15% Zinc.....	—1.02	—0.62	—1.12	—1.55	—1.53	—1.49	—1.54	—0.87	—0.80

It will be noted from Table IV that, in the neutral solutions, the addition of zinc definitely raises the solution potential of aluminum. In alkaline solutions, the potential of aluminum is high and is not raised greatly by the addition of zinc.

In neutral solutions, especially those containing chlorides, the potentials of the aluminum-zinc alloys approach those of zinc. It would also be expected that for equal quantities of current supplied by electrodes of such alloys, the weight of metal consumed would be substantially lower than that of zinc. In laboratory tests of about 100 hours' duration, this expectation was fulfilled. The aluminum-base alloys generally lost less than one-third as much weight as did the zinc. Therefore, from the standpoint of metal consumed, the aluminum-base alloys appear definitely superior to zinc.

The reason that the aluminum does not develop as high a solution potential in many solutions as would be expected from the Electromotive Force Series is probably because aluminum rapidly coats itself with a protective oxide (or other) film upon exposure to many solutions. In alkaline solutions this protective film is not stable, so that the aluminum remains active.

Effect of Alloying on Solution Potentials

The potentials of a series of aluminum-zinc alloy were measured in various solutions. These results are given in Table IV. It can be

Results of Soil Tests

As far as the authors are aware, no long-time tests of the effectiveness of aluminum or aluminum-zinc alloy electrodes in cathodically pro-

TABLE V

Results of Short Time Tests in Soil

Metal or Alloy	Type of Backfill Used	Potential of Test Anode to Remote Earth, Volts	Current Output to Pipe-Milliamperes	Open Circuit Voltage to Pipe, Volts
Aluminum (2S)	Loose Clay	0.70	0.02	0.00
Aluminum + 1% Zinc (72S)	" "	0.80	1.4	0.15
Aluminum + 6.5% Zinc & 0.5% Copper	" "	1.20	14.5	0.25
Zinc	" "	1.06	74.0	0.40
72S (b)	" "	0.91	9.0	0.23
2S	Clay plus 5% sodium chloride	0.90	42.0	0.32
72S	" "	0.99	70.0	0.34
Aluminum + 6.5% Zinc & 0.5% Copper	" "	1.02	92.0	0.33
Zinc	" "	1.10	125.0	0.43
Magnesium	" "	1.75	298.0	1.01
2S	Clay plus 5% sodium chloride and 5% lime	1.37	172.0	0.85
72S	" "	1.38	225.0	0.81
Aluminum + 6.5% Zinc & 0.5% Copper	" "	1.43	142.0	0.71
" " " " " " (c)	" "	1.49	233.0	0.80
Zinc	Clay plus 5% sodium chloride and 5% lime	1.08	98.0	0.36
Magnesium	" "	1.66	293.0	0.98

Notes:— (a) The 2S, 72S and zinc electrodes were sheared from rolled plate. They were ½ x 3 x 36" in size and were used with no special surface treatment. The aluminum alloy containing 6.5% zinc and 0.5% copper and the magnesium were cast and, in most cases, were used with the as cast surface. The cast aluminum alloy electrode was also ½ x 3 x 36" in size but the magnesium electrode was 3 x 3 x 36" in size.
The steel water pipe had a potential of 0.7 volts to a remote copper sulfate electrode.
The pH values of the clay and of the clay-sodium chloride mixture were substantially 7.0, while that of the mixture containing lime was above 10.0.
(b) This 72S electrode had been in the ground for 3 days connected to the water pipe prior to taking these measurements.
(c) After taking a set of measurements with the "as cast" surface still on the cast aluminum alloy, the surface was ground with a mechanical sander to remove the "cast skin".

tecting steel structures buried underground have been completed (2). However, such tests are now under way and initial or short-time results are available. One of these tests was conducted by personnel of the Engineering Department, United Gas Corporation, Houston, Texas. Data from this test are presented here through the courtesy of Mr. C. L. Morgan and Mr. H. M. Fanett.

The test was made at the Distribution Plant of the United Gas Corporation in Houston. The electrodes of the various metals or alloys were tested separately by placing each anode in a hole 4 inches in diameter by 60 inches deep and filling in the hole with various backfill mixtures. Arrangements were made so that the open-circuit potential of each anode to a remote copper sulfate electrode could be measured. Then the current output of each electrode was measured by a zero-resistance milliammeter when the electrode was shorted to a buried steel water pipe. The value of current noted was the fairly constant value obtained in all cases after 5 to 15 minutes. After noting this constant value, the circuit was broken and the potential difference between the electrode and the water pipe was measured. The results obtained and some further data on the tests are given in Table V.

Naturally these short-time results can be taken only as indications, since much longer periods of ex-

posure are required for conclusive information. However, if the results of the short-time test on 72S in loose clay are compared for three days, it can be seen that a higher potential and a larger current were obtained in the case of the test of longer duration. This suggests that the values given for the short-time tests are conservative.

The data in Table V indicate that in the neutral clay soil, the aluminum alloy containing 6.5 percent zinc is superior to both 2S and 72S. In the clay plus sodium chloride, the same general trend is evident, but in this case the aluminum-base alloys compare more favorably with zinc. This comparison is made more favorable if the probable lower metal loss of the aluminum-base alloy compared with zinc for given quantities of current is also taken into account.

In the clay mixture containing sodium chloride and lime, the aluminum-base alloys all develop high potentials and supply large currents. Thus, in this mixture they appear highly promising. In laboratory tests in mixtures of sand, sodium chloride and lime, similar aluminum-base alloys attached to steel corroded at almost 100 percent current efficiency.

Relative Costs of Current Supplied by Various Metal Anodes

Once it is established that each of several metals or alloys will give satisfactory cathodic protection, then the relative costs of the different materials per unit quantity of current supplied are important. A convenient quantity of current to consider is an ampere year. Therefore, in Table VI the costs per ampere year for electrodes of different forms of various metals are given. These calculations are based on 100 percent current efficiency. It will be noted that the cost of current at 100 percent current efficiency from an aluminum anode is definitely lower than that from either magnesium or zinc.

Anodes for Use With Externally Supplied Currents

Through the courtesy of Mr. L. P. Sudrabin, Electro-Rustproofing Company of Dayton, Ohio, we learn that aluminum alloy (17S-T) anodes have been used successfully in the cathodic protection of steel water storage tanks for city and industrial use. In this case, current was supplied either by motor generator sets or by the use of transformers and rectifiers from city power lines. Anodes of steel, cast iron and carbon as well as of

TABLE VI

Approximate Relative Cost of Current Supplied by Various Metal Anodes

(All costs are based on carload lots.)

METAL	Lbs. Metal per Ampere Year	Cost per Ampere Year (100% Current Efficiency) in Dollars			
		Pig (a)	Plate, ½" Thick (b)	Rod, 1½" Diameter (c)	Bar, ½ x 3" Rectangular (d)
Magnesium	8.8	1.804	4.136	3.916	4.444
Aluminum	6.5	0.910	1.378	1.495	1.593
Zinc	23.5	2.174	2.938	3.466	2.938

aluminum have been considered for this application. Steel and cast iron have several disadvantages. The electrochemical equivalent of iron is high (about 20.2 pounds per ampere year). Also, iron or steel anodes of sufficient size to last several years at customary current densities are heavy and, therefore, difficult to install. It was also found that such anodes often developed a localized pitting attack, which is particularly undesirable for such an application. Carbon anodes, because of their mechanical properties, are difficult to install. Thus far, after tests of up to two years' duration, the aluminum alloy anodes have proved the most satisfactory of those tried because of their light weight, low electrochemical equivalent, high current efficiency, and the uniform nature of the attack which occurs.

Summary

Up to the present time, Anodes of zinc have been used the most widely in the cathodic protection of underground steel structures by galvanic action. However, the light metals, aluminum and magnesium, have several theoretical advantages. Both aluminum and magnesium stand higher in the Electromotive Series than zinc. Both of the light metals have substantially lower electrochemical equivalents than zinc. Thus, a 100 percent current efficiency, substantially less weight of aluminum or magnesium would be consumed than that of zinc per ampere year of current supplied. At the present costs of the various metals, assuming 100 percent current efficiency is obtained in all cases, aluminum anodes will supply current at a lower cost than will anodes of either of the other metals.

Because of these fundamental advantages of the light metals, an extensive field investigation of their usefulness in the cathodic protection of underground steel structures is warranted.

Acknowledgment

The data given in Tables III and IV were obtained by Messrs. R. H. Brown and E. T. Englehart at the Aluminum Research Laboratories.

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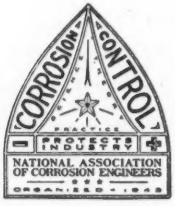
1. L. P. Sudrabin. Water Works and Sewerage, **92**, 16, 1945.
2. DEVELOPING MAGNESIUM FOR CATHODIC PROTECTION. Porter Hart and Yale W. Titterington. Corrosion, **1**, 59 (1945) June.



Use of Zinc for Cathodic Protection

By H. W. Wahlquist
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ZINC ANODES have been used for perhaps 50 or 75 years in marine installations for preventing corrosion of propeller shafts in fittings on the stern of a boat. It is only in recent years, however, that the practicability of using zinc anodes in the cathodic protection of pipe lines has received much attention. Very little information is available in the form of technical publications dealing with the long-time performance of zinc anodes used for cathodic protection in different types of soil, and there appear to be no experience records which might be used as a guide in determining, for example, the ampere hour output which might be expected of zinc anodes for a period of 15 or 20 years or more. Some experimenters have reported the tendency of zinc anodes to become passive after two or three years action in the soil. In other cases the reports show satisfactory performance of zinc anodes in arresting corrosion for periods ranging from three to eight years.

The use of zinc as a current source in cathodic protection has a number of advantages where soil conditions are favorable. The cost of installing and maintaining zinc installations is in general less than the cost of the more usual types of sources such as rectifiers, motor generators, or gas engines. With zinc there are no off-time periods such as frequently occur with gas engines or windmills, a consideration which is usually given too little weight in evaluating the merits of various current sources. Zinc is efficiently adapted for use on either bare or coated pipe lines and provides an economical method of obtaining protection on a line at specific locations which are known to be highly anodic to other sections. These locations are frequently remote from power lines, making it impractical to use rectifiers. Since the zinc anodes serve both as a current source and as a ground bed, the problem of providing and maintaining large masses of metal in extensive ground beds is avoided. By the use of zinc anodes, it is practical to provide protection to coated lines in cities and congested areas without introducing problems of interference to nearby structures.

Concerning the disadvantages of zinc as a current source in cathodic protection installations, perhaps the most important is the lack of information on the long-time performance of zinc in the various types of soil that are encountered. Zinc may not be applicable for use in locations where high soil resistivity limits the current output to small values. In some locations the constituents of the soil may result in the building up of high resistance films which limit the current output to values below the requirements for protection of the lines. With increasing experience in the use of zinc in various types of soils, methods of overcoming these tendencies toward

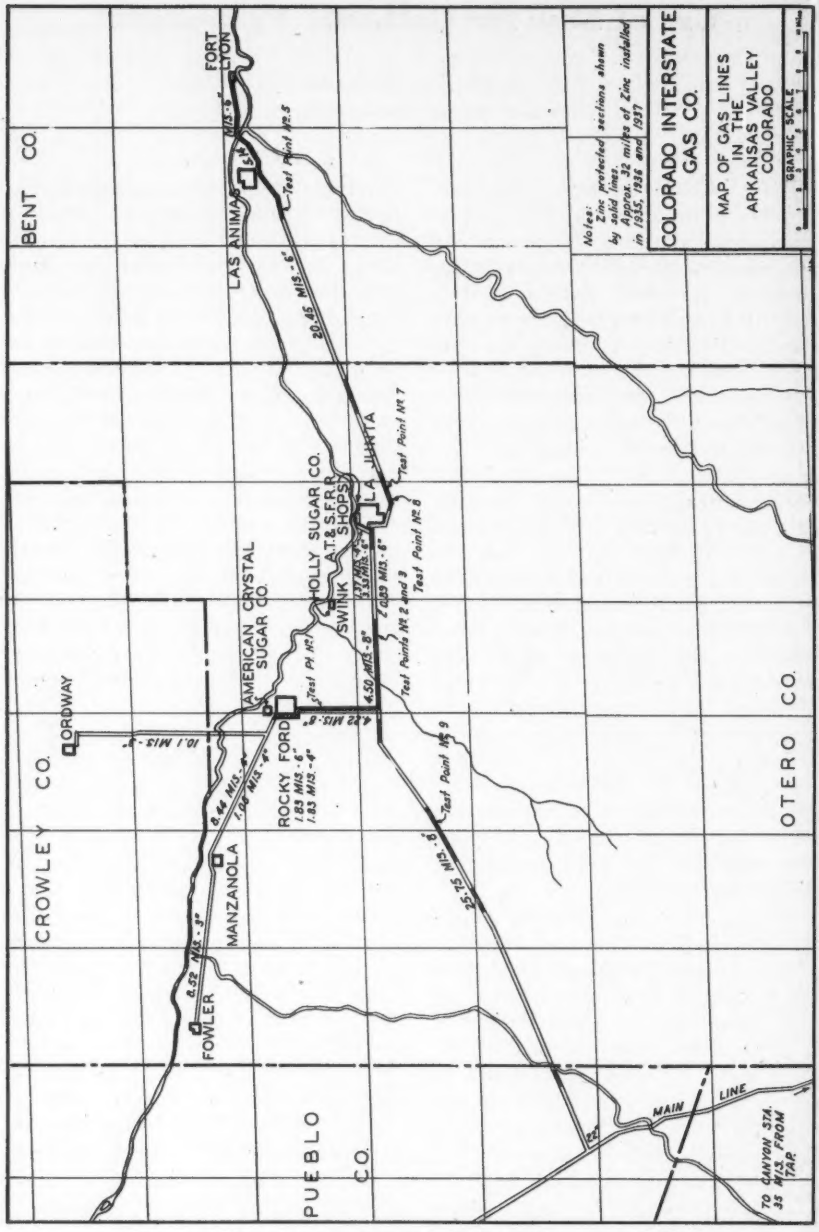


Figure 1. Map of area where zinc rods tested were installed.

passivity will no doubt be found.

The possibilities of using zinc anodes on a large scale for the cathodic protection of pipe lines was discussed by G. I. Rhodes in a paper (1), presented in 1935, and one of the earliest successful installations of zinc on a large scale was reported in a paper (2) by Smith and Marshall of Ford, Bacon & Davis, Inc. This paper describes zinc installations beginning in 1935 on 6-inch and 8-inch welded lines which as a result of highly corrosive conditions had developed numerous corrosion leaks after five years service. A more recent paper (3), by O. C. Mudd on the early use of zinc presents data on the performance of zinc anodes used to cathodically protect a pipe line. Of particular interest in the latter paper is the observation that zinc anodes in soils containing gypsum showed less tendency to become inactive than plates installed in the other soils of the region. A paper (4) by C. L. Brockschmidt describes an installation made in 1939 on an 18-inch pipe line located in severely corrosive soil. The results reported in these papers provide encouraging evidence as to the practicability of using zinc under a wide range of conditions; however, they also illustrate the need for a more intensive study of the long-time behavior of zinc when used as an anode in soil electrolytes. In view of the complicated electrochemical reactions which may result in various soils, a great deal of experimental work by numerous investigators will be required to answer the many questions involved. One notable step in this direction has been taken by the U. S. Bureau of Standards (5) in locating buried zinc-iron couples at a number of points throughout the country to study their behavior in different types of soil. These tests have been in progress since 1941 and should provide some valuable data.

Character of Corrosion Products on Zinc Anodes Buried in Various Types of Soil

One among the problems on which more information is needed concerns the character of the corrosion products that are built up on the zinc surface. Soils which tend to produce insoluble, high-resistance films having low porosity would tend to reduce current output due to increased circuit resistance. If these effects were not too pronounced, some compensation for them might be secured by using anodes having a high ratio of surface area to volume. The resistance to earth of a zinc rod when installed initially is governed by the same laws that apply to driven grounds or other metallic structures in a conducting medium. In the case of rods, for example, the length and soil resistance are the important factors in determining the resistance to earth, the diameter or area being of secondary importance (see Figure 11). These relationships, however, do not apply if the surface of the rod should become coated with a high-resistance film, in which case the area becomes of greater importance and the length and soil resistance of lesser importance in determining the resistance to earth.

If the film has a high porosity, its effect on the resistance tends to be small since the zinc anodes are usually installed in permanently moist earth. The thickness of film

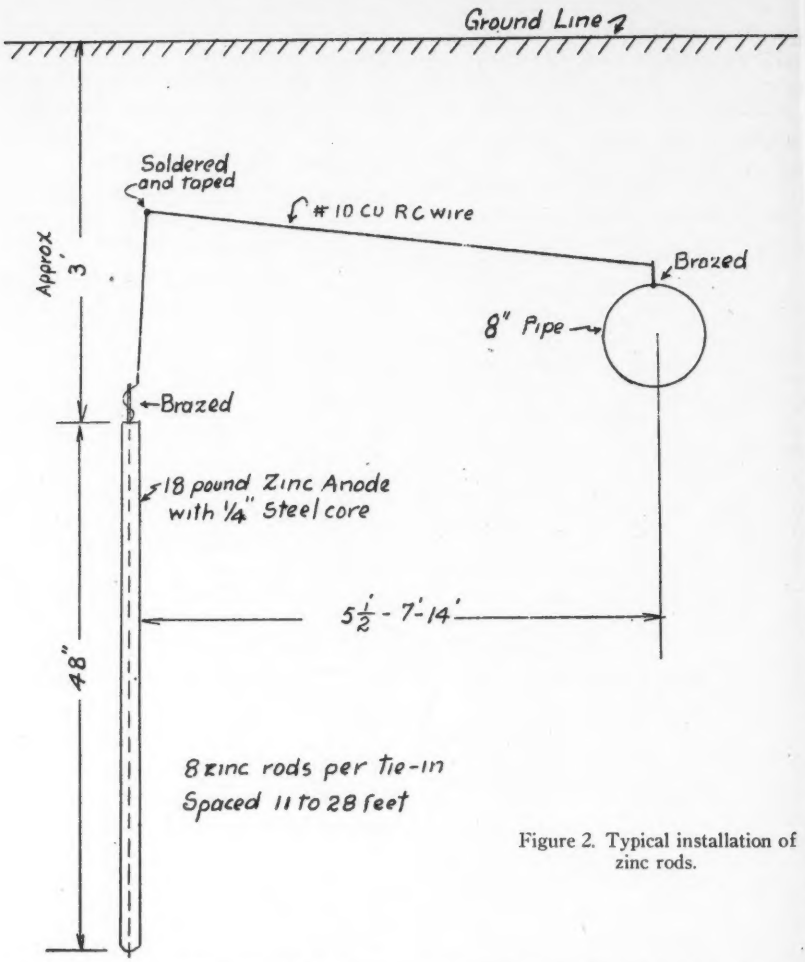


Figure 2. Typical installation of zinc rods.

formations on the surface of the zinc would be influenced by their solubility. Soluble corrosion products would be expected to leach away in porous soils, preventing the build-up of thick films. This leaching action, however, would not be present in tight clay soils where water movement is slow, and probably is not a requirement for the continued action of the zinc so long as the corrosion products have a high porosity and high purity zinc is used.

Changes in Film Potential

The potential of zinc anodes when initially installed in ordinary soils is in the neighborhood of 1.1 volts, measured to a copper-sulphate electrode. A consideration of major im-

portance concerns the possibility that substantial changes may occur in this potential with the formation of corrosion products on the surface of the zinc anode in adjacent soil. A reduction of a few tenths of a volt in the open circuit potential of the zinc anode to the soil would greatly reduce the current output.

For example, consider a zinc anode and iron cathode with open-circuit potentials of 1.1 and 0.6 volts respectively, measured to a copper-sulphate electrode. The difference, 0.5 volt, is the voltage initially available to set up a flow of current when the two electrodes are connected together. As the iron cathode becomes polarized, its potential may increase to say 0.85 volt, leaving 0.25 volt available in the circuit to maintain the current flow. If fouling of the zinc surface should reduce its open circuit potential as much as 0.25 volt, that is from 1.1 to 0.85 volt, no current could be delivered to a cathode having 0.85 volt, and the potential of the iron cathode would drop to a new equilibrium value below the polarization potential necessary to insure protection against corrosion.

It is therefore desirable to determine the types or constituents of soils that tend to reduce the zinc potential and practical methods for counteracting them. The data discussed later in this report show that, for the particular soils tested, the change in the potential of high purity zinc over a period of eight years had been small.

Effect of Impurities in Zinc Anodes

It appears possible that impurities in the zinc could have an effect on the overall behavior of the anodes over a period of time. One possible effect is a reduction in the potential due to the surface becoming fouled with impurities having a lower potential than zinc. The presence of impurities may also increase the local-action currents, with resulting consumption of zinc at a faster rate than that due to the current delivered to the pipe line. If zinc losses from local action in a particular soil are substantial, it may be desirable from this consideration to operate the anodes at a relatively high current density and design an installation on the basis of say five years life instead of ten or twenty years life. On the other hand a high degree of purity in the zinc may be the best solution. Available evidence indicates that zinc losses from local action currents are probably unimportant in the usual types of soil.

Local Action Currents from Different Soil Strata

In a practical installation the zinc anodes are frequently placed in a vertical position and are in contact with soil strata of varying composition, moisture content, and aeration. This introduces possibilities of currents flowing between two parts of the anode exposed to different soils. In this case we are dealing with galvanic currents resulting from the metal's exposure to different electrolytes and this occurs regardless of the purity of the metal. However, where the zinc is delivering an appreciable current to the pipe line, the I R-drops at the zinc surface tend to counteract any tendency for circulating currents between soil strata, the net effect being a variation in the amount of current which the different zinc surfaces deliver to the pipe line.

Effect of Current Density on the Behavior of Zinc Anodes

The matter of current density at the zinc surface may possibly have an important effect on the long-time behavior of the anode. With a high current density the film formation may be too rapid to be dissolved by soil waters; on the other hand, the general reaction at the anode surface would tend to be an increase in the degree of acidity or lowering of pH, and this in turn affects the character and solubility of the corrosion products.

The current density in the initial stages can be controlled to some extent by the spacing, shape, and dimensions of the anodes, or by the use of series resistance. Various practical considerations, however, are involved from the standpoint of installation costs, which limit the degree of freedom in the selection of anode shapes. One form of anode which has been used to a considerable extent consists of a cast zinc rod of cylindrical shape about 1⅜-inch in diameter and 4 feet long, weighing 18 pounds and provided with a ¼-inch steel core. In low-resistance soil of say 500 ohm/cm, the initial output of such a rod when connected to a coated pipe line polarized to say 0.85 volts, is about 80 milliamperes. This represents a current density of 55 milliamperes per square foot of zinc surface. This initial current may reach 200 mils, or 140 mils per square foot with the anode working against a pipe line of 0.5 volt. In one fairly extensive installation in which cylindrical anodes 36 inches long and 7 inches in diameter were used to protect a poorly coated line having a potential of about 0.60 volt, the current density ranged from 27 to 67 mils per square foot of zinc surface.

In still another type of installation employing a group of ten zinc anodes (3 inches wide and 36 inches long) in parallel, spaced 3 feet apart, the current delivered to a coated line of 0.85 volt potential was 300 mils. This corresponds with a current density of 20 mils per square foot of zinc surface.

The current densities encountered in practice probably range from 1 to 200 mils per square foot of zinc surface, the higher densities occurring only where the zinc is connected to an unpolarized line in extremely low-resistance soil. At these higher densities some polarization (approximately 100 millivolts) at the zinc anodes has been observed, resulting in a reduction in the effective voltage available to overcome circuit resistance.

Another factor related to current density is the possibility of depletion of the salts in the soil adjacent the zinc anode. Such an effect might tend to be most pronounced in installations designed to give a high current density. Some resistivity measurements recently made on soil samples taken next to zinc rods which had been operating for eight years at current densities of about 30 milliamperes per square foot, did not show that any marked change in resistivity had occurred over the eight-year period.

Use of Chemical Materials

The use of chemical materials in the soil adjacent the zinc anodes offers possibilities of reducing the tendency of the anodes to become passive where soil conditions are unfavorable. One method which has

been used in a practical installation is discussed in the paper (3), by O. C. Mudd. The method (see Figure 7) consists in the use of gypsum (calcium sulphate) crystals packed around the anodes. Experience with this method extends over a period of about six years. As pointed out in the above paper the low solubility of gypsum prevents the material from leaching away, which is an important practical consideration where chemicals are used in porous soils. Additional data on the use of powdered gypsum mixed with the soil used to backfill the zinc anodes are discussed in subsequent sections of the report.

Certain chemical treatments might be objectionable due to increased zinc losses from local action currents or to the contamination of the soil near the pipe line, introducing possibilities of strong galvanic couples.

Tests on Zinc Protected Lines of the Colorado Interstate Gas Company

The zinc anode installations in Colorado, on gas pipe lines of the Colorado Interstate Gas Company, have been in service from six to eight years. G. R. Olson of the United Gas Pipe Line Company, in discussing the performance of these zinc installations with engineers of the Colorado company arranged for a field study of the present conditions. K. H. Logan of the U. S. Bureau of Standards agreed to participate in the tests, which were carried out during the period from November 17 to November 26, 1943.

A map of the sections of lines where zinc rods have been installed

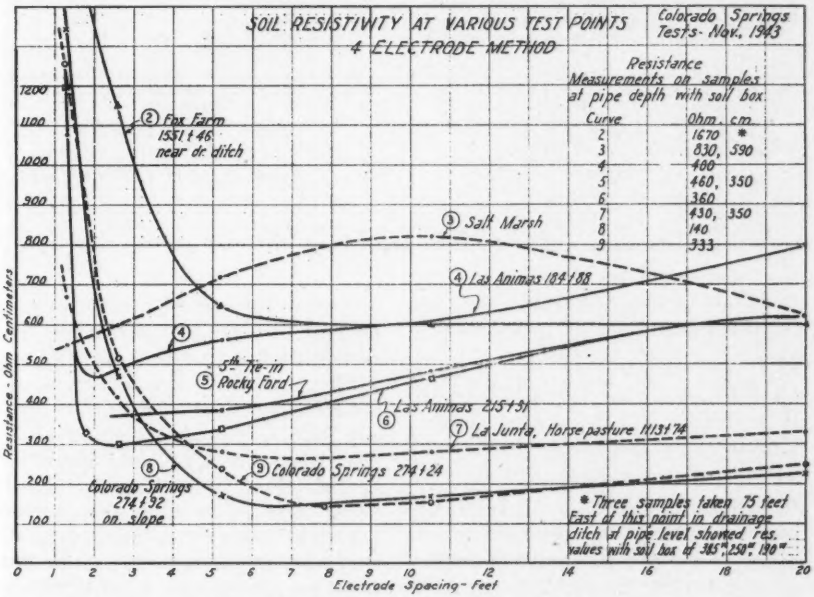

SOIL RESISTIVITY AT VARIOUS TEST POINTS
4 ELECTRODE METHOD
Colorado Springs Tests - Nov. 1943
Resistance Measurements on samples at pipe depth with soil box
Curve Ohm. cm
2 1670 *
3 830, 590
4 400
5 460, 350
6 360
7 430, 350
8 140
9 333
② Fox Farm 155 I 46 near dr. ditch
③ Salt Marsh
④ Las Animas 184188
⑤ 5th Tie-in Rocky Ford
⑥ Las Animas 215191
⑦ La Junta, Horse pasture 113174
⑧ Colorado Springs 274192 on slope
⑨ Colorado Springs 274124
* Three samples taken 75 feet East of this point in drainage ditch at pipe level showed res. values with soil box of 385, 250, 190
Resistance - Ohm Centimeters
Electrode Spacing - Feet

Figure 3. Soil resistivity at various points.

TABLE I

Condensed Summary of Measurements—Colorado Springs Tests, November, 1944

DS No. Test Point	Location of Test Point		Date Installed		Spacing of Zinc Rods		Pipe		Soil at Pipe Level	Soil Resistivity—Electrode Spacing			
	Line	Station No.	Pipe	Zinc	Bet. Rods Ft.	To Pipe Ft.	Size In.	Coating		15 In.	3 Ft.	5 Ft.	10 Ft.
1	Rocky Ford Lateral	5th Tie-in Sta. 164+00 approx.	1929	1935	10	5	8	Cold Coat	Wet Brown Clay with Alkali	....	370	370	460
1	" "	6th Tie-in	1929	1935	10	5	8	"	" "	....	370	370	460
2	La Junta Branch	Fox Farm 1551 + 46 (Pipe in ditch)	1929	1935	10	5	8	Cold Coat	Brown Sandy Clay with Alkali	2500	1000	660	620
				1941	10	5							
3	" "	1552 + 27	1929	"	10	5	8	"	" "	....	1100	620	530
5	Las Animas Lateral	Salt Marsh 964 + 46	1929	1936	28	14	6	Cold Coat	Wet Brown* Sandy Clay with Alkali	550	620	700	600
				1941	14	14							
7	" "	215 + 31 King Arroyo Ditch	1929	1937	14	7	6	Cold Coat	Wet Brown* Sandy Clay with Alkali	1200	300	330	440
7	" "	214 + 16	1929	1937	14	7	6	"	" "	....	....	....	....
8	" "	184 + 88	1929	1940	14	7	6	Cold Coat	Very Hard Brown Clay with Alkali	1080	500	560	600
9	La Junta Branch	Horse Pasture 1113 + 74	1929	1937	11	5½	8	Cold Coat	Brown* Sandy Clay Fairly Moist	675	390	290	275
11	Colorado Springs Lateral	Pring Ranch 274 + 24	1931	1937	11	5½	8	Enamel	Brown Sandy Clay with Alkali	1200	450	240	160
12	" "	274 + 92	1931	1935	11	5½	8	Enamel	" "	1320	400	180	155
	" "	Tie-ins No. 3, 4, 5, 6 ‡	1931 1937	1935 1935	11	5½	8	Enamel Bare	Swampy	2000 [11] with canes			

Note:—Numbers in parentheses refer to the sample number of the soil or zinc rod.
* Black soil around pipe at location of 1941 leak—showed presence of sulphides in HCl acid test and lead acetate paper.

is shown on Figure 1. The first installations were made in the fall of 1935 near Rocky Ford and La Junta on lines laid in 1929, using rather thin-walled pipe and a cold coat of bituminous paint. Reconditioning of some sections of pipe had become necessary in 1934, as a result of numerous leaks in locations where highly corrosive soil existed. In the spring of 1935, corrosion leaks were developing at such a rapid rate that cathodic protection with zinc anodes was applied to avoid a more extensive reconditioning program.

The zinc rods used in the earlier installations were one inch square and four feet long, weighing about twelve pounds each and having a ¼-inch steel core. Later installations were made with round rods 1⅜-inch in diameter and four feet long, cast from electrolytic zinc and weighing 18 pounds. Figure 2 illustrates a typical insallation. Eight

TABLE I
Continued

Ohm/Cm Soil Box		Soil pH Indicator Papers		POTENTIAL Pipe to Soil		POTENTIAL Zinc to Soil			No. Zinc Rods	Zinc Output		Resistance	
				Over Pipe	Remote Earth	Over Pipe	Remote Earth			Total	Per Rod	Pipe	Zinc
Next to Zinc	Near Pipe	Next to Zinc	Near Pipe	Volts $CuSO_4$	Volts Electr.	Volts $CuSO_4$	Volts Electr.	Z/P		Milliamperes		†Ohms	†Ohms
.....	360	....	Alk.	0.95	0.93	1.09	1.07	0.15	8	280	35	0.017	0.51
350 (No. 2)	460 (No. 1)	Acid	....	0.97	0.93	1.09	1.06	0.139	8 (No. 1	228	28	....	0.58
.....	1670 (No. 3)	....	....	0.84	0.83	1.03	1.10	0.295	16	480	30	0.03	0.55
250 385 (No. 5, 7)	190 (No. 6)	Acid Acid	Alk.	0.85	0.82	1.06	1.08	0.285	16 (No. 2)	470	29	0.02	0.55
590 (No. 12)	830 (No. 9, 11) 590 (No. 10)	Acid	Alk. Alk. Alk.	0.84	0.77	1.09	1.02	0.274	16 (No. 3) (1936)	725	45	0.023	0.37
570 (No. 14)	360 (No. 13)			0.57	0.60	0.99	1.02	0.452	8 (No. 4)	410	51	0.03	1.03
.....	....	....	....	0.47	0.59	0.94	1.06	0.485	8 (No. 5)	220	28	0.023	2.2
400 (No. 15)				0.54	....	1.02	....	0.52	8 (No. 6)	285	36	....	1.8
220 270 (No. 16, 17)	430 350 (No. 18, 19)			0.55	0.64	1.0	1.09	0.48	8 (No. 7)	240	30	0.03	1.8
333 (No. 21)				0.64	....	1.02	....	0.37	8	327	41	0.05	1.08
140 (No. 20)	....	Alk.	Alk.	0.64	....	0.65	....	0.008	8 (No.8,9)	10	1	Loose Unsoldered Connections	
				0.72	....	1.07	....	0.39	32	940	29		

† Includes lead to pipe (about 7 feet No. 10 Cu) Except for Rocky Ford Lateral Measurements.
‡ Values are average for four tie-ins after connecting two groups which were found open.

rods were connected together with a No. 10 rubber-covered copper wire and each group was connected to the pipe line with a single drain wire. The spacings employed between the rods and to the pipe are shown on Table I.

A considerable amount of data on the zinc outputs and potentials had been obtained during the first two years that the zinc anodes were in service. The tie-in connections were then permanently buried and further tests were largely confined to measurements of pipe-to-soil potentials using the Rhodes steel electrode. Examples of these early data are presented in Tables IV and IV A, and Figures 5 and 6.

The data on Table I summarize the results of the 1943 tests at seven locations. The soil in general, at the pipe level, was a brown sandy clay with inclusions of white alkali salts, and of low resistivity. Of particular interest on this table are the measure-

TABLE II

Record of Leaks on Sections Investigated in Colorado Zinc Tests

Note:—This record includes all leaks which have occurred within 500 feet of the point investigated.

No. of Leaks	Size of Pipe, (In.)	Station	Date of Leak	Date Zinc Installed	No. of Mos. Since Zinc Installation
La Junta Lateral:					
Horse Pasture:					
1	8	1113+79	1- 2-41	8-37	40
Fox Farm:					
2	8	1552+46	7- 3-41	8-35	82
1	8	1552+47	11-19-43	8-35	99
1	8	1554+65	8-12-40	8-35	60
1	8	1554+68	6- 4-39	8-35	46
1	8	1557+59	9-28-42	8-35	85
Las Animas Lateral:					
1	6	185+21	9-16-43	6-40	39
1	6	185+22	8- 6-40	6-40	2
1	6	185+23	9-16-43	6-40	39
2	6	185+25	12- 1-43	6-40	42
1	6	185+35	9-22-42	6-40	27
1	6	185+37	9-22-42	6-40	27
1	6	185+40	9-22-42	6-40	27
1	6	185+43	9-22-42	6-40	27
1	6	185+96	12-12-39	6-40	..
1	6	215+30	9-22-42	7-37	62
1	6	215+31	9-16-43	7-37	74
1	6	215+32	1-29-43	7-37	19
2	6	215+40	9-15-43	7-37	74
2	6	215+42	9-21-42	7-37	62
1	6	215+45	9-21-42	7-37	62
1	6	215+47	9-21-42	7-37	62
1	6	215+49	9-21-42	7-37	62
1	6	215+49	9-15-43	7-37	74
1	6	215+50	6-24-42	7-37	60
1	6	215+55	8- 7-40	7-37	15
1	6	215+65	8- 7-40	7-37	15
1	6	215+65	1-29-43	7-37	19
1	6	216+01	8-16-40	7-37	15
1	6	216+04	1-29-43	7-37	19
1	6	216+09	7- 3-40	7-37	36
1	6	216+28	12- 5-39	7-37	29
1	6	216+29	1- 3-41	7-37	41
1	6	959+96	9-24-42	7-36	82
1	6	960+01	6- -38	7-36	23
1	6	960+02	1-26-43	7-36	78
1	6	960+25	6- -38	7-36	23
1	6	960+37	2-24-38	7-36	19
1	6	961+61	2-12-36	7-36	..
1	6	964+43	3-14-41	7-36	56
1	6	964+86	3-15-39	7-36	32
1	6	964+90	3-15-39	7-36	32
1	6	965+09	10-28-38	7-36	27
1	6	965+10	5- 8-41	7-36	58
1	6	965+10	9-14-43	7-36	86
1	6	965+17	6- -38	7-36	23
1	6	965+50	6- -38	7-36	23
3	6	965+53	6- -38	7-36	23
1	6	965+57	6-12-39	7-36	35
1	6	965+60	6-12-39	7-36	35
1	6	965+67	12- 5-39	7-36	41
1	6	965+82	10-28-38	7-36	27
1	6	965+86	6-12-39	7-36	35
1	6	967+09	6- -38	7-36	23
1	6	969+00	12- 9-35	7-36	..
21	6	960+00 to 970+00	12-18-35	7-36	..

Note:—More zinc was added to this section in 1941.

Colorado Springs Lateral:

No leak records are available, but it is known that at least 25 leaks developed in a length of some 300 feet in 1937. Five leak clamps were used in 2½ feet in bottom of draw. This pipe was replaced with new pipe laid bare in 1937, from Station 273+60 to 276+60. No leaks have developed since then.

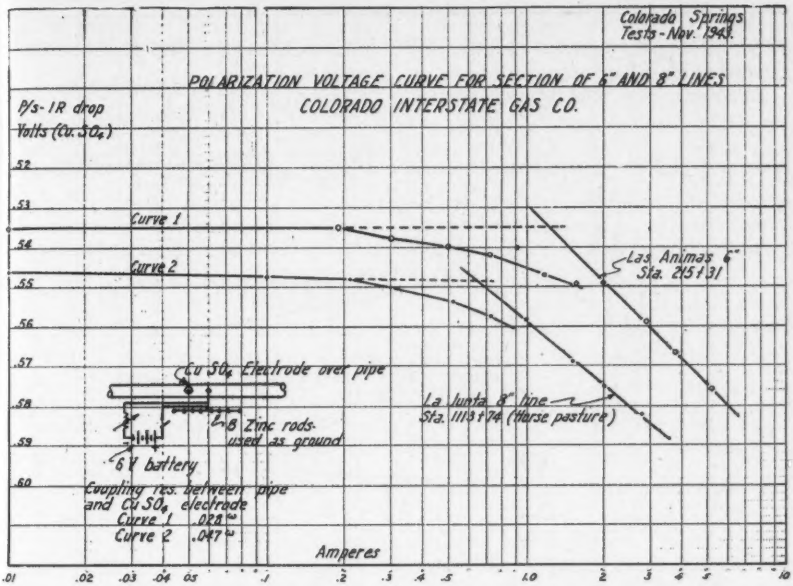
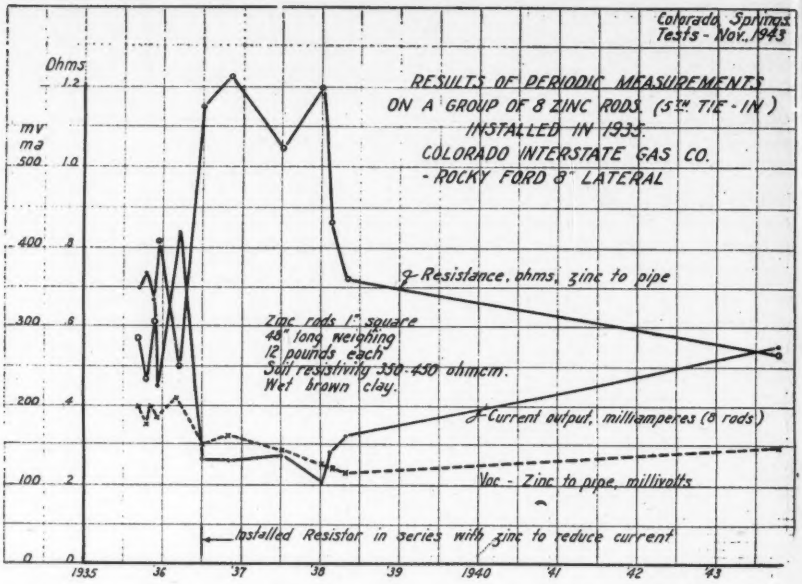

Colorado Springs Tests - Nov. 1943.
POLARIZATION VOLTAGE CURVE FOR SECTION OF 6" AND 8" LINES
COLORADO INTERSTATE GAS CO.
P/s - IR drop
Volts (Cu SO4)
.52
.53
.54
.55
.56
.57
.58
.59
.60
Curve 1
Curve 2
Las Animas 6" Sta. 215 + 31
Cu SO4 Electrode over pipe
La Junta 8" line Sta. 1113 + 74 (Horse pasture)
8 Zinc rods used as ground
6 V battery
Coupling res. between pipe and Cu SO4 electrode
Curve 1 .028 Ω
Curve 2 .047 Ω
Amperes
.01 .02 .03 .04 .05 .1 .2 .3 .4 .5 1.0 2 3 4 5 10

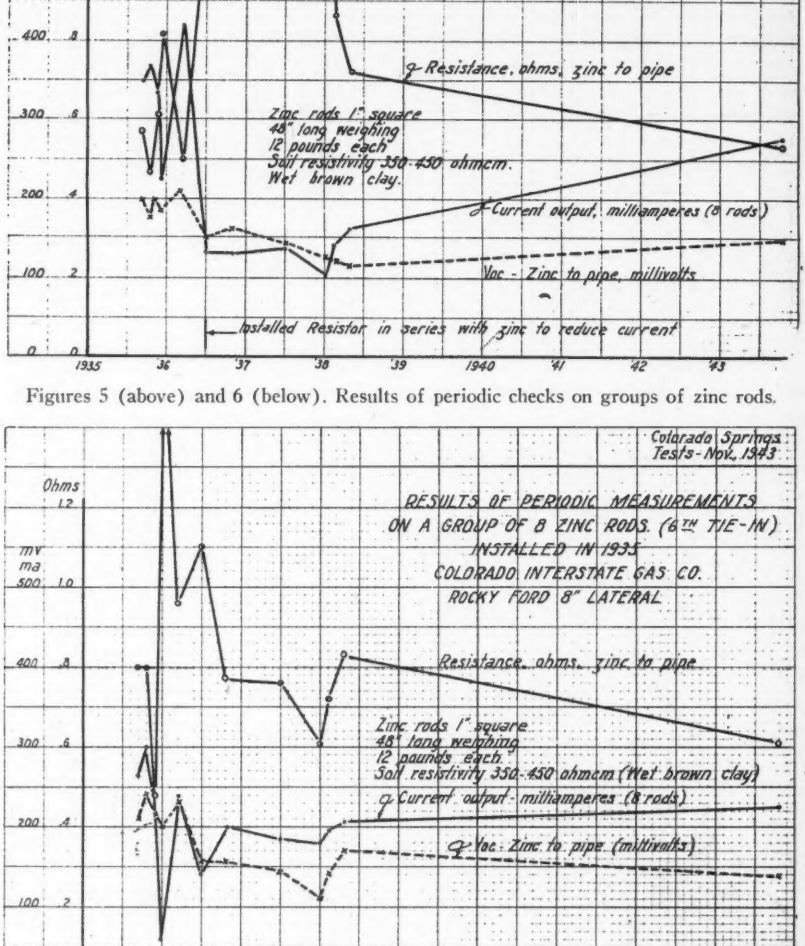
Figure 4. Polarization voltage curve for section of line under test.

ments of zinc output current and open circuit voltage. The first ten tie-ins on which measurements were made showed the zinc anodes delivering values of current averaging 35 milliamperes per rod corresponding with a current density of 24 milliamperes per square foot of zinc area. The oldest of these rods (test points 1 and 2) have been in service since 1935, or about eight years. The open-circuit voltage readings between the zinc and a remote copper sulphate electrode average 1.06 volts, which is within about 40 millivolts of the potential of a new zinc rod free from corrosion products. These results together with the measurements made shortly after the installation (Table IV, Figures 5 and 6) indicate a remarkable stability in the zinc performance over the eight-year period.

The results for test point 12 and tie-ins 3, 4, and 5 were adversely affected by loose, unsoldered joints, three out of the five tie-ins being completely open. At location 12, two rods removed from tie-in 2, which had developed an open circuit, showed the zinc entirely consumed for a length of about 24 inches on the bottom half of the rod, the total loss of weight being 7 pounds 10 ounces for one rod and 5 pounds for the other. The lower half of these rods was in an extremely low resistance stratum of soil (140 ohm/cm) and reference to Table IV A shows a high current output for the two-year period that test data are available. The predominant salt in the low-resistance stratum was identified in Bureau of Standards tests as sodium sulphate. A single new rod at this location, backfilled with clay



Figures 5 (above) and 6 (below). Results of periodic checks on groups of zinc rods.



mud, showed a current output of 291 milliamperes and a zinc-to-soil potential of 1.10 volts. The theoretical life of a 12-pound rod at this output would be less than two years. The upper part of each of the two rods removed at this location had nearly the original size which is an indication that the circuit had been open for several years.

At location 3, a comparison was made of the outputs of two rods in the same group, one installed in 1935 and the other in 1941, with the following results:

Year Installed	Rod Weight and Shape	Current Output Ma.	Z/P Volts	Resistance Ohms	Soil Next to Rod Ohm/Cm
1935	12 lbs. Square	21	0.172	8.2	385
1941	18 lbs. Round	38.5	0.172	4.5	250

These results indicate the resistance of the older rod had increased substantially over the eight-year period. The soil was carefully excavated for the full length of the 1935 rod on one side to permit a close inspection of the conditions with the rod in place. Upon first inspection the rod appeared like new, having its original shape and being covered with a thin gray metallic film exactly resembling clean zinc. Removing the soft film exposed alternate layers of mushy, white and gray-and-pink corrosion products, extending nearly to the steel core, the zinc being largely consumed. The soil ($R = 380$ ohm/cm) for a distance of about six inches from the rod was hardened and had a lighter color than the soil farther away. This 12-inch cylinder of soil surrounding the zinc rod had numerous inclusions of white material resembling alkali. Immediately next to the zinc, however, an acid reaction was obtained with indicator papers. It was observed that considerable void space existed along the rod, permitting the rod to be moved about 1/16-inch from side to side. It is possible that this could partially account for the higher measured resistance of the older rod as compared with the newer rod, rather than the effect of the thick layer of porous corrosion products which had been built up.

At location 5, an excavation was made to the pipe at a location where a leak had occurred two years previously; and masses of black soil mixed with brown clay and sand were found. The black soil is reported to be characteristic of conditions existing near a leak in these alkali soils. An acid (hydrochloric) test on the black soil showed the presence of sulphides by hydrogen sulphide evolution and darkening of lead acetate paper. This would ordinarily be considered a positive test for the presence of active anaerobic bacteria, but in this case it is not known whether the sulphide resulted from bacterial activity or from the action of the leaking gas on the soil.

A similar but extreme blackening of the soil was observed at location 9, near a former leak. In this case the soil was completely black for about two feet from the pipe. On excavating one of the zinc anodes 5½ feet from the pipe the black soil was again encountered surrounding

TABLE III

Soil Samples Obtained During November, 1943, Tests on Colorado Interstate Lines

Soil Sample Number	LOCATION	Resistance (Soil Box) Ohm/Cm	pH with Indicator Papers
1	Rocky Ford Lateral 6th Tie-in, 18″ from Zinc Rod Sample 1	460W	Alk
2	Rocky Ford Lateral 6th Tie-in, next to Zinc Rod	354W	Sl Acid
3	La Junta 8″ line—Station 1551 x 46 Soil next to pipe 4′ depth	1670W	.....
3A	Same as (3) except top soil	.....	.....
4A	Corrosion products of rod Sample 1	.....	.....
5	La Junta 8″ line—Station 1552 x 27 next to two-year old zinc rod	250W	Sl Acid
6	Same as (5) except 18″ from zinc rod	192W	Alk
7	Same as (5) except next to 7 year old zinc rod Sample 2	384W	Sl Acid
8	Alkali from bank of Timpon Creek	.....	Alk
9	Las Animas—Salt Marsh—black soil next to pipe near former leak, Station 964 x 46	830W	Alk
10	Same location as (9) except 8 feet from pipe, brown clay loam, and sand with alkali specks	590W	Alk
11	Same as (10) except 18″ from zinc rod	830W	Alk
12	Same as (11) except 3″ from zinc rod	590W	Sl Acid
13	Las Animas 6″ Extension—Station 215 x 31, 30″ from zinc rod Sample 4	360W	.....
14	Same as (13) except next to zinc rod	570W	.....
15	Las Animas 6″—Station 184 x 88, next to zinc rod sample 6 (3 years)	400W	.....
16	La Junta 8″—Horse pasture, Station 1113 x 74, next to zinc rod sample 7	220W	.....
17	Same as (16) except 18″ from zinc rod	270W	.....
18	Same as (16) except next to pipe, 3′ depth	430W	.....
19	Sandy clay turned black from 1941 gas leak—showed sulphide test with H cl (H_2S evolution and darkening of lead acetate paper)	350W	.....
20	Colorado Springs 8″, Station 274 x 92, next to 8 year zinc sample 8, 5′ from surface	140W	Alk
21	Colorado Springs 8″—Station 274 x 24, soil @ 3½′ depth	333W	.....

Zinc Rod Samples Obtained During November, 1943, Tests of Colorado Interstate Lines

Sample Rod Number	LOCATION	Date Installed	Output at time of Removal Milli-amperes
1	Rocky Ford—6th Tie-in	1935	29
2	La Junta 8″—Station 1552 x 27 Fox Farm	1935	21
3	Las Animas 6″—Salt Marsh	1936	41
4	Las Animas 6″—Station 215 x 31	1937	33
5	Las Animas 6″—Station 214 x 16	1937	25
6	Las Animas 6″—Station 184 x 88	1940	46
7	La Junta 8″—Station 1113 x 74 Horse pasture	1937	45
8	Colorado Springs 8″—Station 274 x 92	1935	0 (Connection open)
9	Colorado Springs 8″—Station 274 x 92	1935	0 (Connection open)

the tie-in lead to the pipe, which the escaping gas had followed. Samples of this soil wrapped in wax paper were observed about a week later and the outside surface had returned to its normal brown clay color indicating oxidation of the sulphides. This oxidation had progressed about ⅛ inch into the body of the soil. An interesting formation was observed in the soil surrounding the zinc anode that was dug up at this point. Looking down on the zinc rod the soil surrounding the rod for a distance of 7 inches showed about 25 annular rings of different shading, resembling the rings on a tree stump. The extreme outside ring had a gray metallic appearance having the color of zinc.

The zinc anode removed at this location showed a total weight loss of 10 pounds 13 ounces. The rod had been in service for 6 years and at the time of removal was delivering 45 milliamperes to the pipe line.

At this rate the theoretical consumption of zinc calculates to be 6 pounds 6 ounces for a 6-year period. The average current output over the 6-year period is not known. Chemical analysis of a soil sample taken at this location showed 5 percent calcium sulphate and 6 percent calcium carbonate.

At location 7 another comparison was made between two zinc rods, one installed in 1937, and the other a new rod from stock. The data for these two rods follow:

Year Rod Installed	Current Output Ma.	Z/P Volts	Ohms	Soil Next to Rod Ohm/Cm
1937	33	0.365	11	570
1943	65	0.475	7.3	Same

Here again the results indicate some increase in the resistance to earth of the older rod which was completely encased in a thick coating of corrosion products. However, the output of the particular rod selected is considerably lower than the average (51 milliamperes) for the complete group of eight rods, and a smaller difference in the resistance would no doubt have been obtained with other rods.

Particular notice was taken of the condition of the rubber insulation on the wires connecting the plates. The insulation, reported to be a 30 percent para grade, was found to be in excellent condition with no sign of deterioration. Rubber stripped off the wire had an elasticity comparable with that of an ordinary rubber band.

The pipe-to-soil potentials measured on these lines were highest at test point 1 on the Rocky Ford Lateral. The measurements to a remote ground (about 300 feet) indicate that this section of line is effectively insulated from adjoining sections, possibly as a result of couplings installed during the reconditioning of some adjoining sections. At this location there have been no corrosion leaks since the line was installed in 1929. A record of the leaks experienced on the sections tested is presented on Table II, and here summarized.

At two points where low potentials were measured, data were taken to determine the break in the polarization curve using the eight zinc anodes as a ground bed. The results of these tests, presented on Figure 4, indicate higher current requirements than the current delivered by the zinc at this point.

Record of Leaks 500 Feet Either Side of Test Point

Test Point	1938	1939	1940	1941	1942	1943	Total
1	0	0	0	0	0	0	0
2 & 3	0	1	1	2	1	1	6
5	11	6	0	2	1	2	22
7	0	1	4	1	7	7	20
8	0	1	1	0	4	4	10
9	0	0	0	1	0	0	1
11 & 12	0	0	0	0	0	0	0
Tie-ins 3, 4, 5 & 6	25 leaks in 300-foot section in 1937 and 300 feet replaced with new bare pipe. No leaks since 1937.						

TABLE IV

Colorado Interstate Gas Company
Zinc Rod Installation—Rocky Ford Test Section—8-Inch Line
1" Square by 4' Zinc Rods spaced about 10' and drained in groups of 8.

Station No.	PIPE-TO-STEEL ELECTRODE POTENTIALS—(Millivolts)									
	Mar. 8th, 1938	Feb. 8th, 1938	June 7th, 1937	Nov. 10th, 1936	June 10th, 1936	Mar. 13th, 1936	Dec. 10th, 1935	Nov. 5th, 1935	Sept. 24th, 1935	Aug. 27th, 1935
1	300	295	173				205	156	162	154
	240	250	180				185	150	150	160
	220	225	160				235	174	148	146
	220	250	168	185	145	220	180	152	138	136
	215	210	158				215	184	136	132
	195	205	149				205	156	140	140
	225	210	164				185	158	152	142
	205	205	170				190	154	144	170
2	220	200	170				205	162	170	130
	225	210	170				180	144	138	136
	195	195	164				180	128	110	122
	210	220	167	165	115	115	200	194	124	130
	205	250	164				210	154	140	140
	200	250	164				235	184	128	138
	200	225	162				210	156	128	134
	205	250	168				195	84	84	110
3	300	255	168				210	138	104	116
	325	245	164				195	168	118	142
	310	220	167				220	158	134	146
	280	250	165	290	130	175	220	154	138	152
	310	215	171				215	154	168	148
	270	220	160				185	140	120	150
	230	235	155				225	142	118	134
	235	250	156				235	182	137	142
4	220	255	225				230	164	132	146
	260	250	210				235	150	122	126
	250	140	245				175	102	42	146
	245	215	206	200	150	195	200	110	46	160
	240	220	225				220	186	114	130
	210	225	220				220	100	50	110
	225	220	210				180	194	110	130
	255	240	225				240	180	144	120
5	265	205	144				170	112	104	130
	200	215	155				165	106	104	80
	245	220	136				140	102	38	60
	225	210	138	165	150	210	145	88	30	84
	230	205	142				170	106	76	80
	255	210	138				195	94	30	36
	240	215	137				140	68	34	78
	230	235	148				165	82	84	92
6	235	245	141				106	52	32	84
	240	200	138				165	62	+16	48
								96	30	
	235	200	147	160	155	230	185	70	08	56
	210	240	155				180	100	4	66
	250	300	158				185	82	22	34
	215	200	152				100	94	5	60
	225						135		7	68
	225	205	155				110	60		
7	210	215	153				165	56	24	78
	220	195	159					82	42	70
	240	195	160				140	76	14	92
	210	140	155	190	155	230	90	54	22	56
	210	170	140				155	94	32	86
	200	160	133				70	32	15	68
	185	175	118				85	92	36	78
	200	160	146				55	24	12	66
8	210	130	139				80	0	24	90
	185	205	132				65	38	40	88
	160	170	129				155	30	+ 5	68
	195	160	124	200	160	255	55	42	32	70
	190	135	128				50	52	3	90
	220	195	127				105	52	32	90
	210	185	136				125	02	56	102

Rocky Ford Test Section

OPEN CIRCUIT VOLTAGE—Millivolts—8 RODS IN PARALLEL

Sta. No.	Mar. 8th, 1938	Feb. 8th, 1938	Jan. 6th, 1938	June 7th, 1937	Nov. 10th, 1936	June 10th, 1936	Mar. 13th, 1936	Dec. 10th, 1935	Nov. 5th, 1935	Sept. 24th, 1935	Aug. 27th, 1935	Nov. 19th, 1943
1	155	125	110	131	155	140	150	130	160	160	150	
2	125	115	115	120	165	135	145	125	153	145	145	
3	140	125	125	122	180	150	175	140	150	155	145	
4	150	135	138	141	150	150	195	150	165	170	170	
5	115	120	125	141	160	150	210	185	200	175	200	150
6	170	140	110	141	155	155	230	200	215	240	210	139
7	160	150	130	138	190	155	230	205	225	240	206	
8	145	160	125	154	200	160	255	215	185	240	195	

MILLIAMPERES CURRENT DRAINED—8 RODS IN PARALLEL

1	80	50	255	185	190	170	310	210	330	440	440	
2	290	245	270	265	160	170	360	150	410	430	450	
3	300	250	273	273	170	200	360	?	405	470	450	
4	150	115	115	150	90	150	340	190	350	400	420	
5	160	140	105	135	130	130	420	225	330	370	350	275
6	205	195	180	185	200	140	240	60	245	300	263	224
7	200	195	170	185	200	220	230	160	235	260	230	
8	180	65	45	75	60	150	180	140	250	200	180	

G. R. Olson
July, 1940.

Limited chemical analyses made on two of the soil samples that were taken during these tests are as follows:

	Soil Sample No. 1 Rocky Ford Test Point 1 Percent	Soil Sample No. 17 LaJunta Branch Horsepasture Test Point 9 Percent
Water soluble sulphates (SO_3)	0.35	3.28
Total sulphates (SO_3)	0.39	3.66
Water soluble calcium (CaO)	0.17	1.91
Total calcium (CaO)	4.85	5.39
Hypothetical Combinations:		
Calcium sulphate ($CaSO_4$)	0.48	5.28
Sodium sulphate (Na_2SO_4)	0.21	0.99
Calcium carbonate ($CaCO_3$)	8.25	5.72

It is planned to obtain additional chemical analyses on the soil samples that were taken, also analyses of the corrosion products on several zinc anodes.

Tests on Zinc Protected Lines in Houston

Table V presents a summary of tests on 43 zinc installations on coated gas lines in Houston. As indicated on the table, these installations have been in operation for periods ranging from two to nine months. Typical methods of installation are illustrated on Figure 8.

Referring to Figure 5, it will be observed that the soil resistance at the zinc level is fairly low, but higher than the average value of 450 ohms encountered in the Colorado tests. The majority of the installation has been made in vertical shafts containing four or five zinc plates. The average current density of 16 milliamperes per square foot is relatively low since the lines are metallically insulated from adjacent structures which permits them to build up a polarization potential, thereby reducing the net voltage Z/P and

TABLE IV-A
Zinc Output and Potential Record of Colorado Springs Lateral

	CURRENT IN MILLIAMPERES								OPEN CIRCUIT VOLTAGE IN MILLIVOLTS							
	1935				1936				1935				1936			
Station	Sept. 25	Oct. 10	Nov. 8	Dec. 6	Jan. 11	Mar. 5	April 6	May 15	Sept. 25	Oct. 10	Nov. 8	Dec. 6	Jan. 11	Mar. 5	April 6	May 15
1	570	530	480	450	360	540	380	115	165	150	140	150	150	205	135	145
2	325	370	320	285	320	300	300	290	150	145	135	140	145	165	135	150
3	110	115	55	60	125	100	120	150	130	120	100	220	130	120	115	125
4	100	120	95	110	150	120	110	130	135	130	105	250	125	185	120	125
5	120	100	70	80	95	50	50	90	135	125	100	240	120	125	105	130
6	115	80	53	60	60	80	70	80	140	120	120	125	130	120	115	140
7	105	80	80	....	55	50	50	90	140	130	120	....	145	120	115	150
8	70	75	55	....	40	50	45	75	140	135	120	....	125	125	120	125
9	75	65	50	....	0	40	....	60	150	145	125	....	125	120	....	135
10	60	50	35	20	30	40	20	45	140	145	130	120	125	120	120	135
11	40	30	40	40	20	40	50	50	125	145	130	130	120	120	115	125
12	30	25	25	20	40	25	30	20	145	140	125	120	120	115	115	125

	PIPE-TO-SOIL POTENTIAL IN MILLIVOLTS												
	1935					1936						1942	
STATION	(1) Sept. 20	Sept. 25	Oct. 10	Nov. 8	(2) Dec. 6	Jan. 11	(3) Mar. 5	April 6	May 15	1938 Oct. 20	1940 June 7	1941 April 15	April 10	No 2
1	+162	—220	—162	—200	—160	—250	—215	—255	—175	—98	—90	.....	—80	.....
2	+150	—194	—190	—195	—192	—220	—210	—180	—195	—90	—50	—330	—95	+13
3	+164	—210	—210	—182	.....	—210	—200	—180	—200	—76	—32	—85	—104	+34
4	+162	—162	—132	—185	—198	—200	—200	—195	—190	—126	—70	+210	—80	+73
5	+156	—200	—205	—200	—225	—205	.....	—190	—195	—110	—81	—350	—94	—36
6	+158	—196	—220	—195	—225	—195	.....	—190	—190	—88	—78	—112	—87	+32
7	+104	—192	—184	—200	.....	—320	.....	—185	—175	—106	—41	—106	—80	— 9
8	+116	—240	—168	—210	.....	—195	.....	—175	—185	—192	—31	—184	—47	+39
9	+65	—240	—110	—235	.....	—175	.....	.....	—160	—240	—48	—300	—63	+38
10	.....	—260	—215	—220	—180	—185	.....	—170	—180	—270	—51	—230	—76	—71
11	.....	—310	—280	—360	—205	—230	.....	—170	—180	—310	—76	—156	—56	—116
12	.....	—340	—330	—325	—70	—205	.....	—170	—190	—300	—76	.....	.....	.....

[1] Just before zinc was installed.
[2] Some sections were under water, hence no readings were taken.
[3] No readings on some sections, due to frozen ground.

TABLE V
Summary of 43 Zinc Installations on Coated Gas Lines Houston Tests, March, 1944

	Zinc Plates Per Installation No.	Soil (26) Res. at Zn Level Ohm/Cm	Depth of Boring Feet	Res. to Grd. of Zinc Ohms	Months in Operation as of Jan. 1944	Current Output Milliamperes		Current Density Zn Surf. Ma/Sq. Ft.	POTENTIAL—VOLTS			
						Per Instln.	Per Plate		† P/S	† Z/S	‡ Z/P	Z/S† at Time Installed
Max.	28	1200*	23	4	9	350	39	29	1.01	1.14	0.34	1.18
Min.	5	280	6	.55	2	55	6	4.4	0.74	1.01	0.14	1.04
Avg.	9.7	600*	14	1.1	4.5	195	22	16	0.88	1.07	0.24	1.12

Effective area of zinc plate = 1.35 sq. ft. per plate (making allowance for reduction due to enamel strip)
Total No. Zinc Plates = 417.
Total Output of 417 plates = 8.4 amp.

Notes:—
⧗ All zinc plates are 36 inches long, 3 inches wide, ½ inch thick, weighing 14 lbs. each. Plates are located in vertical boring 3½ inches in diameter, with from 1—5 plates in a single boring, depending on the depth. Backfill clay mud or clay mud mixed with gypsum plaster.
⧗ Refers to number of installations included in averages.
* Excluding a few measurements on strata of high resistance quicksand at the bottom of the boring.
† Pipe-to-soil and open circuit zinc-to-soil potential measurements to remote (approx. 100 ft.) copper sulphate electrode.
‡ Zinc-to-pipe potential measured about 1 second after opening circuit.

output current. Comparing the open circuit zinc potential Z/S, measured at the time installed, with those measured after several months operation, an average reduction of 50 millivolts has occurred. This reduction is observed soon after the zincs have been in operation and is probably a stable value which will continue at approximately this level during the life of the anodes.

Table VI illustrates the type and resistivity of the soil encountered at various levels in two vertical borings where zinc anodes were installed. The calculated values of resistance shown at the bottom of the table were determined from Figure 11 and the average soil resistivity.

Table VII shows a comparison of the current outputs of zinc plates backfilled with clay mud only and plates backfilled with a mixture of clay mud and gypsum plaster. In all cases the output is higher where gypsum is used in the backfill. The amount of gypsum added is usually in the ratio 1½ gallons gypsum to 8 gallons of clay mud, thoroughly mixed with sufficient water to a consistency that will just pour. The resistivity of the mixture ranges from 250 to 400 ohm/cm.

Measurements on Special Test Zinc Plates

In order to obtain some information on the behavior of zinc anodes in varied environments a number of special test plates have been buried where frequent observations of current, potential, and resistance can be made. Table VIII presents the results of a recent set of measurements on this group of zinc plates. The plates are permanently connected through a common lead to the water pipe which provides a low resistance structure having a fairly stable potential to earth. The character of the backfills used in these installations is shown in Table IX, along with measurements of resistivity. The low resistance backfills given by ammonium chloride, hydrochloric acid and sodium hydroxide are expected to exaggerate the losses resulting from local action currents.

TABLE VI

Examples of Soil Resistivity Measurements in Borings at Two Different Locations Using Four Terminal Soil Box—Houston Tests, March, 1944

	LOCATION NO. 1		LOCATION No. 2	
Depth	TYPE SOIL	Res. Ohm/Cm	TYPE SOIL	Res. Ohm/Cm
1′	Black clay loam	1440	(Under pavement)	
2′	Black clay loam	740		
3′ 6″	Dark gray clay	600	Yellow and black clay	680
4′ 6″	Dark gray clay	500	Yellow and black clay	540
5′ 6″	Dark gray clay	500		
6′ 6″	Light gray clay (some Caliche rock)	800	Yellow and gray clay	500
8′	Light gray clay (not as much Caliche)	640	Gray clay—yellow streaks	380
9′ 6″	Tan and gray clay	720	Gray clay—yellow streaks	370
11′	Same with some sand and water	770	Gray and tan clay—some red (mottled)	440
12′ 6″	Same with more sand	1100	Gray and tan clay—some red (mottled)	400
14′	Quick sand	2000	Gray and tan clay—some red (mottled)	380
15′	Quick sand	3300	Gray and tan clay—some red (mottled)	480
18′			Gray and tan clay—some red (mottled)	480
19′ 6″			Same with some sand	820
	Average 2 ft. to 14 ft. level	840	Average 3 ft. 6 in. to 19 ft. 6 in. level	500
	Meas. res. of stack of 4 zinc plates	2.5^{W}	Meas. res. of stack of 5 zinc plates	1.1^{W}
	Calc. Meas. res. of stack of 4 zinc plates	2.0^{W}	Calc.. res. of stack of 5 zinc plates	0.97^{W}

EXPERIENCE WITH ZINC ANODES
Levee or Depression To Hold Run-off Water Over Anode Hole.
No. 4 or 6 B.C. Stranded copper wire.
Gravel backfill in Anode hole.
Rocks Tamped in side of hole to expand but allow water storage space.
Crushed Gypsum, moist, tamped solidly around Anode at least 6" from inside.
Zinc Anode.
Connections imbedded in hot paint for moisture.
See Detail "A"
Detail "A"
Detail "B"
Current test leads attached to ground surface
1 M.F. per Amp. Shunt
Terminal Brazed, welded or soldered to pipe
Construct form from Pipe to ground surface. Backfill around form and fill with hot paint.
Note: Forms to be constructed of hot paint to allow at least 2" of connections to allow at least 2" of ground bare wire or connections.
FIG. No. 7
See paper by O.C. Hoad "Experience with Zinc Anodes" May-1943
Cylinder to be made from 1/4" Electrolytic Zinc.
#8-D.B., B.C. Stranded Copper Wire 76" long (Includes 15" to be soldered to Zinc)
Wire to be soldered along 15" to inside of cylinder.
Wt. of Zinc Approx. 44 Lbs.
Wire to be coiled inside of cylinder when shipped or handled.

TABLE VII

Comparison of Current Outputs of Zinc Plate* Installations Backfilled with Clay Only and with Clay Mixed with Gypsum Plaster—Houston Tests, March, 1944

DS	No. Months Connected	Backfill	Depth of Hole, Ft.	No. Plates	I ma	Current in Percent of Total
188	5	Gypsum	15	4	113	57
	5	Gray & Red Clay		4	87	43
164	6	Gypsum	20	5	104	58
	6	Red Clay		5	82	46
137	7	Gypsum	15	4	168	61
	7	Red Clay		4	104	38
126	8	Gypsum	15	4	57	52
	8	NH_4Cl		4	27	25
	8	Red & Gray Clay		4	25	23
111	9	Gypsum	6	5	118	75
	9	White Clay		6	38	24
112	9	Gypsum	6	5	105	50
	9	Clay		5	102	49
w	9	Gypsum	4	1	65	58
	9	Gray Clay		1	47	42
106	9	Gypsum	6	1	27	60
	9	Gray Clay		1	18	40

* Zinc plates are 36 in. long, 3 in. wide and ½ in. thick buried vertically in holes 3½ inches in diameter.

TABLE VIII

Comparison of Current Outputs of Single Test Zinc Plates with Various Types of Backfill Houston Tests, March, 1944

(Measurements With Only One Plate Connected to Water Pipe.)

Plate No.	No. Months Connected	Backfill* Gray Clay Mixed with	** I ma	† Z/S Volts	‡ Resistance ohms	Current in Percent of Value at time of Installation	Division of Current With all Plates Connected to Water Pipe ma	Voc mv
1	9	Crushed Gypsum	78	1.10	6.2	82	44	265
2	10	Black Clay Loam	24	1.07	19	48	10	197
3	8	Gypsum Plaster	105	1.11	4.7	91	66	290
4	8	Lime	14	.73	7.9‡	25	4	25
5	8	Ammonium Chloride	54	.95	6.1‡	34	27	175
6	8	Gray Clay	90	1.09	5.2	75	50	250
7	6	Hydrochloric Acid	97	1.09	4.9	77	61	286
8	6	Sodium Hydroxide	102	1.09	4.6	47	62	280
9	11 days	Gypsum plaster & sand	102	1.12	4.9	103	56	266
10	11 days	Gyp Plaster Sand & $MgSO_4$	119	1.13	4.3	103	73	305
11	11 days	Gyp Plaster & $ZnSO_4$	87	1.13	5.9	97	57 Meas. Total 504	330

Note:—All plates are rolled zinc 36 in. long, 3 in. wide and ⅛ in. thick.

* All plates except No. 2 were buried in vertical holes drilled to a depth of 4 feet. The borings, which were chiefly gray clay, were thoroughly mixed with the chemicals and water to a consistency that would just pour. For Plate No. 1 the hole was about 18 in. in diameter and filled with gray clay and crushed gypsum wall board. The holes for the other plates were 3½ in. diameter. Plate No. 2 was placed in a horizontal position about 8 inches below the surface.

** Short circuit current to water pipe in milliamperes.

† Zinc to soil potential measured to remote $CuSO_4$ electrode about 1 second after opening circuit.

‡ Circuit resistance. Resistance of water pipe and connecting lead approximately 0.2 ohm.

‡ Rapid depolarization—actual resistance substantially less than this.

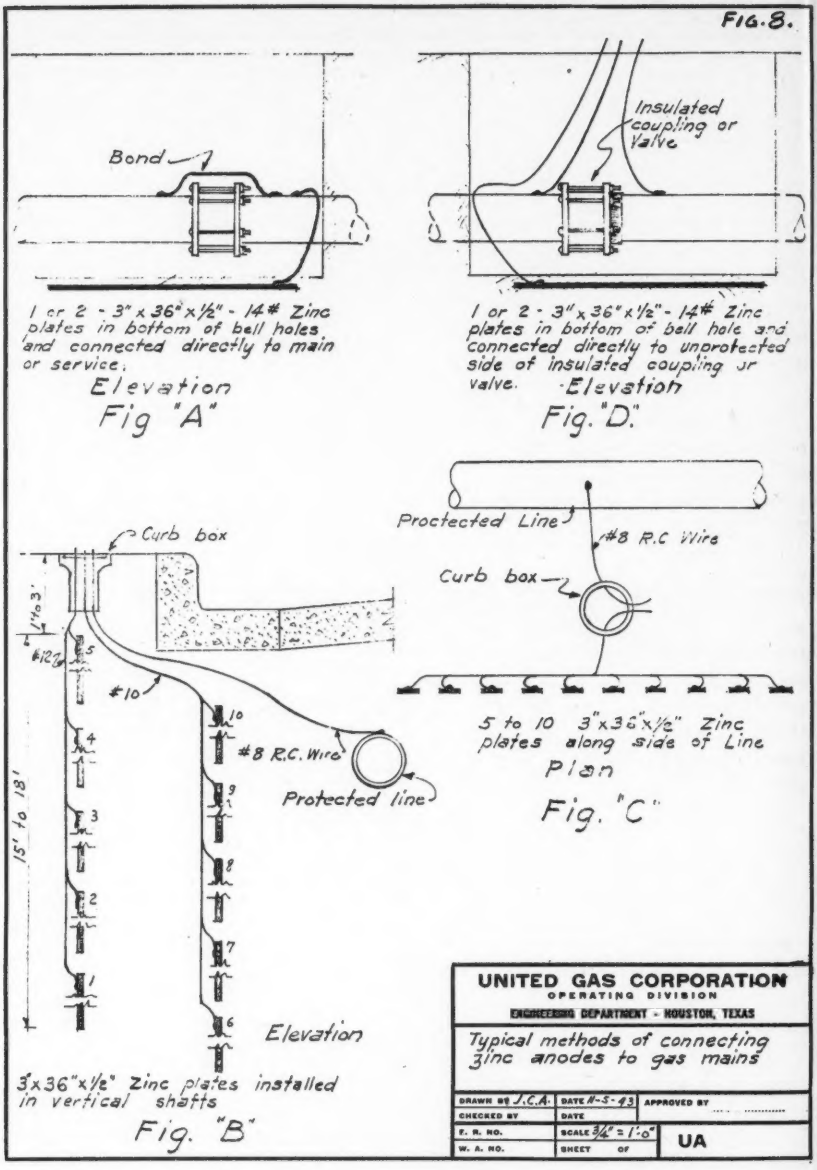


FIG. 8.
Bond
1 or 2 - 3" x 36" x ½" - 14# Zinc plates in bottom of bell holes and connected directly to main or service.
Elevation
Fig "A"
Insulated coupling or Valve
1 or 2 - 3" x 36" x ½" - 14# Zinc plates in bottom of bell hole and connected directly to unprotected side of insulated coupling or valve.
Elevation
Fig. "D"
Curb box
#12
#10
#8 R.C. Wire
Protected line
15' to 18'
Elevation
3" x 36" x ½" Zinc plates installed in vertical shafts
Fig. "B"
Protected Line
#8 R.C Wire
Curb box
5 to 10 3" x 36" x ½" Zinc plates along side of Line
Plan
Fig. "C"
UNITED GAS CORPORATION
OPERATING DIVISION
ENGINEERING DEPARTMENT - HOUSTON, TEXAS
Typical methods of connecting zinc anodes to gas mains
DRAWN BY J.C.A.
DATE 4-5-43
APPROVED BY
CHECKED BY
DATE
F. R. NO.
SCALE 3/4" = 1'-0"
W. A. NO.
SHEET OF
UA

Figure 8. Typical methods of connecting zinc anodes to gas mains, showing method of bonding across couplings and use of insulated couplings to sectionalize line.

TABLE IX

Resistivity of Backfills of Special Test Zinc Plates at Time of Installation Houston Tests, March, 1944

Zinc Plate No.	Backfill Gray Clay Mixed With	Amount of Chemical per Gallon of Clay Mud*	Resistivity Ohm/Cm
1	Crushed Gypsum		(approx.) 600
2	Black Clay Loam		1200
3	Gypsum Plaster	1 quart $CaSO_4$	400
4	Lime	1 quart $Ca(OH)_2$	....
5	Amm. Chloride	½ pound NH_4Cl	25
6	Gray Clay		600
7	Hydrochloric Acid	¼ pint 35% HCl	66
8	Sodium Hydroxide	½ pound NaOH	36
9	Gypsum Plaster and Sand	1 quart $CaSO_4$ 1 gallon sand	500
10	Gypsum Plaster Sand & $MgSO_4$	1 quart $CaSO_4$ 1 gal. sand ½ lb $MgSO_4$	100
11	Gypsum Plaster & $ZnSO_4$	1 quart $CaSO_4$ ¼ pound $ZnSO_4$	300

* Approximately two gallons of mud mixture for each zinc plate except for No. 1 and No. 2, which were backfilled without added water.

Note:—The general soil resistance at the zinc plate level ranged from approximately 1000 ohm/cm near the top of the plate to 600 ohm/cm at the bottom of the plate (4-ft. depth).

Referring to Figure 8, the best performance from the standpoint of stability and current output so far is given by plate 3 backfilled with clay mud mixed with powdered gypsum. The next best, from the stability standpoint is given by plate 1, backfilled with clay and crushed gypsum wall board. It is probable that better results for plate 1 would have been secured if gypsum crystals had been packed around the plate similar to the method used by Mr. Mudd (Figure 7). The poorest performance is given by plate 4, backfilled with a clay-lime mixture, and by plate 5, backfilled with a clay ammonium chloride mixture. In both of these plates polarization is very pronounced, the open-circuit voltage and current of the lime plate in particular being reduced to very small values. This is probably similar to the effects noted by some observers in which zinc plates buried in soil of high calcium carbonate content developed a hard, impervious carbonate scale which resulted in the anodes becoming passive. A mixture of powdered calcium carbonate

TABLE X

Comparison of AC and DC Resistance Measurements on Special Test Zinc Plates Houston Tests, March, 1944

Plate No.	Backfill (Gray Clay Mixed with)	DC Voc/ISC	Resistance Ohms AC	Ratio DC/AC
1	Crushed Gypsum	6.6	6.0	1.10
2	Black Clay Loam	24.	21.	1.14
3	Gypsum Molding Plaster	4.6	4.4	1.04
4	Lime	8.1	5.4	1.50*
5	Ammonium Chloride	6.2	4.1	1.51*
6	Gray Clay	5.8	5.0	1.16
7	Hydrochloric Acid	5.1	4.7	1.08
8	Sodium Hydroxide	4.5	4.3	1.05
9	Gypsum Plaster & Sand	5.0	4.8	1.04
10	Gypsum Plaster, Sand & $MgSO_4$	4.2	4.0	1.05
11	Gypsum Plaster & $ZnSO_4$	6.2	6.1	1.02
	Group 1–11 in parallel	0.77	0.71	1.08

* These two plates depolarize rapidly when circuit is opened.
Voc Measured about one second after circuit was opened.

TABLE XI

Measurements on Special Test Zinc Plates at Warehouse

(See Fig. for data on grouping and soil resistivity)

TYPE BACKFILL	Zinc Plate No.	1943 July 26	1943 July 30	1943 Sept. 14	1943 Oct. 12	1943 Nov. 4	1943 Dec. 15	1944 Feb. 3	1944 Feb. 5	1944 Feb. 19	1944 Mar. 2	1944 Mar. 7	1944 Mar. 18	1944 Mar. 30
SHORT CIRCUIT CURRENT TO WATERPIPE (ONLY TEST ZINC CONNECTED) MILLIAMPERES														
Crushed Gyp & Clay	1	50	95	55	45	81	70	73	71	70	72	72	78	72
Black Clay Loam	2	25	50	15	22	38	Open	Open	20	22	20	19	24	18
Gyp, Mold, Plast & Clay	3	65	115	72	66	110	90	80	88	94	100	101	105	103
Lime & Clay	4	90–55	55	27	12	31	42	17	14	13	14	14	14	12
NH_4Cl & Clay	5	145	160	96	80	110	35	52	54	54	58	56	54	50
Gray Clay	6	90	120	63	64	93	72	82	81	79	80	79	90	78
HCl & Clay	7	..	..	125	96	125	100	77	78	83	86	87	97	88
NaOH & Clay	8	..	..	215	31	85	65	89	90	95	99	100	102	100
Gyp, Sand & Clay	9	..	..	..	..	..	..	..	..	..	..	99	102	95
Gyp, Sand, Clay & $MgSO_4$	10	..	..	..	..	..	..	..	..	..	..	115	119	115
Gyp, Clay & $ZnSO_4$	11	..	..	..	..	..	..	..	..	..	..	90	87	80
OPEN CIRCUIT VOLTS TO WATERPIPE														
Crushed Gyp & Clay	1	0.53	0.53	0.55	0.55	0.53	0.54	0.50	0.50	0.50	0.50	0.49	0.48	0.49
Black Clay Loam	2	0.50	0.51	0.52	0.53	0.51	Open	Open	0.46	0.46	0.47	0.45	0.45	0.44
Gyp, Mold, Plast & Clay	3	0.57	0.54	0.54	0.55	0.54	0.55	0.52	0.51	0.51	0.51	0.49	0.49	0.49
Lime & Clay	4	0.77	0.51	0.40	0.38	0.45	0.57	0.14	0.13	0.11	0.11	0.12	0.11	0.10
NH_4Cl & Clay	5	0.53	0.53	0.52	0.52	0.50	0.51	0.40	0.41	0.39	0.39	0.37	0.33	0.32
Gray Clay	6	0.53	0.53	0.54	0.54	0.53	0.54	0.50	0.50	0.49	0.49	0.47	0.47	0.47
HCl & Clay	7	.....	.....	0.60	0.54	0.53	0.56	0.49	0.50	0.49	0.49	0.47	0.47	0.47
NaOH & Clay	8	.....	.....	0.90	0.30	0.50	0.55	0.49	0.49	0.49	0.49	0.47	0.47	0.47
Gyp, Sand & Clay	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.52	0.50	0.50
Gyp, Sand, Clay & $MgSO_4$	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.55	0.51	0.51
Gyp, Clay & $ZnSO_4$	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.53	0.51	0.51
RESISTANCE—OHMS* ZINC TO WATERPIPE														
Crushed Gyp & Clay	1	10.6	5.6	10.	12.	6.6	7.7	6.8	7.	7.1	7.	6.8	6.2	6.8
Black Clay Loam	2	20.	10.2	35.	24.	13.	.....	.....	23.	21.	23.	24.	19.	24.
Gyp, Mold, Plast & Clay	3	8.8	4.7	7.5	8.3	4.9	6.1	6.5	5.8	5.4	5.2	4.9	4.7	4.8
Lime & Clay	4	9.	9.3	15	32.	15.	14.	8.2	9.3	8.5	7.9	8.6	7.9	8.3
NH_4Cl & Clay	5	3.7	3.3	5.4	6.5	4.6	15.	7.7	7.6	7.2	6.7	6.6	6.1	6.4
Gray Clay	6	5.9	4.4	8.6	8.4	5.7	7.5	6.1	6.2	6.2	6.2	6.0	5.2	6.0
HCl & Clay	7	.....	.....	4.8	5.6	4.2	5.6	6.4	6.4	5.9	5.7	5.4	4.9	5.3
NaOH & Clay	8	.....	.....	4.2	9.7	5.9	8.5	5.5	5.4	5.2	5.0	4.7	4.6	4.7
Gyp, Sand & Clay	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.3	4.9	5.2
Gyp, Sand, Clay & $MgSO_4$	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.8	4.3	4.4
Gyp, Clay & $ZnSO_4$	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.9	5.9	6.4
	P/S													
	W.P.	0.56	.....	0.54	0.55	0.57	0.56	0.60	0.59	0.59	0.59	0.61	0.62	0.61
CURRENT OUTPUT—MILLIAMPERES—WITH GROUP CONNECTED TO WATER PIPE														
Crushed Gyp	1	30	55	40	30	45	.....	48	47	45	46	40	44	41
Black Clay Loam	2	9	19	10	14	15	.....	Open	8	10	9.5	9	10	8
Gyp, Mold, Plast & Clay	3	41	70	55	45	62	.....	47	55	58	61	64	66	66
Lime & Clay	4	15	12	5	4	6	.....	4	4	3	3.5	3	4	3
NH_4Cl & Clay	5	100	94	63	49	50	.....	28	25	26	27.5	26	27	24
Gray Clay	6	51	66	47	37	44	.....	51	48	44	44	44	50	44
HCl & Clay	7	.....	.....	not	66	72	.....	50	48	51	53	55	61	56
NaOH & Clay	8	.....	.....	meas.	11	39	.....	63	56	58	60	62	62	63
Gyp, Sand & Clay	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	55	56	54
Gyp, Sand, Clay & $MgSO_4$	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	72	73	72
Gyp, Clay & $ZnSO_4$	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	59	57	53
Total	Group	255	310	380	245	325	245	285	290	298	302	490	504	490
		Dry Weather	Heavy Rains on July 28 & 29	Installed Plates No. 7 & 8. Loose Joint in Water Pipe	Dry Weather	Heavy Rains Nov. 2 & 3. Plates Disconnected	Plates Have Been Disconnected Since Nov. 4	Several Rains During Month of Jan. Used Res. Amm.	Wet Weather	Wet Weather	Wet Weather	Installed Plates No. 9, 10 & 11. New Lead to Water Pipe	Wet Weather	No Heavy Rain Since March 18 Surface Dry

* Derived from Voc/ISC, Values for Plates No. 4 & No. 5 substantially higher than true resistance due to rapid depolarization when circuit is opened.

TABLE XI (Continued)

TYPE BACKFILL	Zinc Plate No.	1943 July 26	1943 July 30	1943 Sept. 14	1943 Oct. 12	1943 Nov. 4	1943 Dec. 15	1944 Feb. 3	1944 Feb. 5	1944 Feb. 19	1944 Mar. 2	1944 Mar. 7	1944 Mar. 18	1944 Mar. 30
OPEN CIRCUIT VOLTAGE TO WATER PIPE AND REST OF GROUP—VOLTS														
Crushed Gyp	1	.....	.....	.....	.....	.....	.....	0.317	.....	0.310	0.310	0.270	0.265	0.272
Black Clay Loam	2	.....	.....	.....	.....	.....	.....	Open	.....	0.220	0.215	0.205	0.197	0.208
Gyp, Mold, Plast & Clay	3	.....	.....	.....	.....	.....	.....	0.308	.....	0.295	0.290	0.295	0.290	0.295
Lime & Clay	4	.....	.....	.....	.....	.....	.....	0.04	.....	0.020	0.025	0.022	0.025	0.025
NH_4Cl & Clay	5	.....	.....	.....	.....	.....	.....	0.220	.....	0.170	0.195	0.190	0.175	0.180
Gray Clay	6	.....	.....	.....	.....	.....	.....	0.280	.....	0.260	0.255	0.255	0.250	0.253
HCl & Clay	7	.....	.....	.....	.....	.....	.....	0.310	.....	0.290	0.280	0.290	0.286	0.290
NaOH & Clay	8	.....	.....	.....	.....	.....	.....	0.325	.....	0.260	0.280	0.285	0.280	0.283
Gyp, Sand & Clay	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.300	0.266	0.272
Gyp, Sand, Clay & $MgSO_4$	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.340	0.303	0.308
Gyp, Clay & $ZnSO_4$	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.350	0.330	0.330
Total	Group	0.530	.....	0.610	0.510	0.510	.....	0.468	0.470	0.475	0.470	0.470	0.467	0.470
RESISTANCE TO WATER PIPE AND REST OF GROUP—OHMS*														
Crushed Gyp	1	.....	.....	.....	.....	.....	.....	6.6	.....	6.9	6.8	6.8	6.0	6.6
Black Clay Loam	2	.....	.....	.....	.....	.....	.....	Open	.....	22.0	23.0	23.0	20.0	26.
Gyp, Mold, Plast & Clay	3	.....	.....	.....	.....	.....	.....	6.6	.....	5.1	4.8	4.6	4.4	4.5
Lime & Clay	4	.....	.....	.....	.....	.....	.....	10.0	.....	7.0	7.2	7.3	6.3	8.3
NH_4Cl & Clay	5	.....	.....	.....	.....	.....	.....	7.9	.....	6.5	7.1	7.3	6.5	7.5
Gray Clay	6	.....	.....	.....	.....	.....	.....	5.5	.....	5.9	5.8	5.8	5.0	5.8
HCl & Clay	7	.....	.....	.....	.....	.....	.....	6.2	.....	5.7	5.4	5.3	4.7	5.2
NaOH & Clay	8	.....	.....	.....	.....	.....	.....	5.2	.....	4.5	4.7	4.6	4.5	4.5
Gyp, Sand & Clay	9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	4.8	5.0
Gyp, Sand, Clay & $MgSO_4$	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.7	4.2	4.3
Gyp, Clay & $ZnSO_4$	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.9	5.8	6.2
Total	Group	2.1	.....	1.6	2.1	1.57	.....	1.64	1.62	1.6	1.55	0.96	0.93	0.96
P/S Water Pipe to	Zn off	0.56	.....	0.54	0.55	0.57	0.56	0.60	0.59	0.59	0.59	0.61	0.62	0.61
$CuSO_4$ Elect. Volts	Zn on	.....	.....	0.75	0.68	.....	0.68	0.75	0.75	0.73	0.75	0.70	0.72	0.70
Group Z/S Volts	Zn off	1.09	.....	1.15	1.06	1.08	1.08	1.07	1.07	1.06	1.07	1.08	1.09	1.07
Res. of WP (incl. Lead)	Ohms	.....	.....	0.55	0.53	.....	0.49	0.53	0.55	0.47	0.53	0.19	0.20	0.19
		Dry Weather	Heavy Rains on July 28 & 29	Installed Plates No. 7 & 8. Loose Joint in Water Pipe	Dry Weather	Heavy Rains Nov. 2 & 3. Plates Disconnected	Plates Have Been Disconnected Since Nov. 4	Several Rains During Month of Jan. Used Res. Amm.	Wet Weather	Wet Weather	Wet Weather	Installed Plates No. 9, 10 & 11. New Lead to Water Pipe	Wet Weather	No Heavy Rain Since March 18 Surface Dry

* Derived from Voc/ISC. Values for Plates No. 4 & No. 5 substantially higher than true resistance due to rapid depolarization when circuit is opened.

and soil would have been a closer representation of the field conditions, and it is planned to include this in the group, along with a mixture of calcium carbonate and gypsum. It appears that gypsum tends to counteract the tendency for carbonate films to form on the zinc surface. Hydrochloric acid tests on numerous soil samples in the Houston area have shown the presence of carbonates in the soil, sometimes in the form of limestone or caliche rock and sometimes in the form of white powdery inclusions. Analysis of one soil sample at the 9-foot level showed 3 percent calcium carbonate and 0.06 percent calcium sulphate.

The dc resistances given on these tables were derived from the ratio of the open-circuit voltage to the short circuit current. Where polarization effects are pronounced, such as in the case of plates 4 and 5, the resistance values so obtained are substantially higher than the values

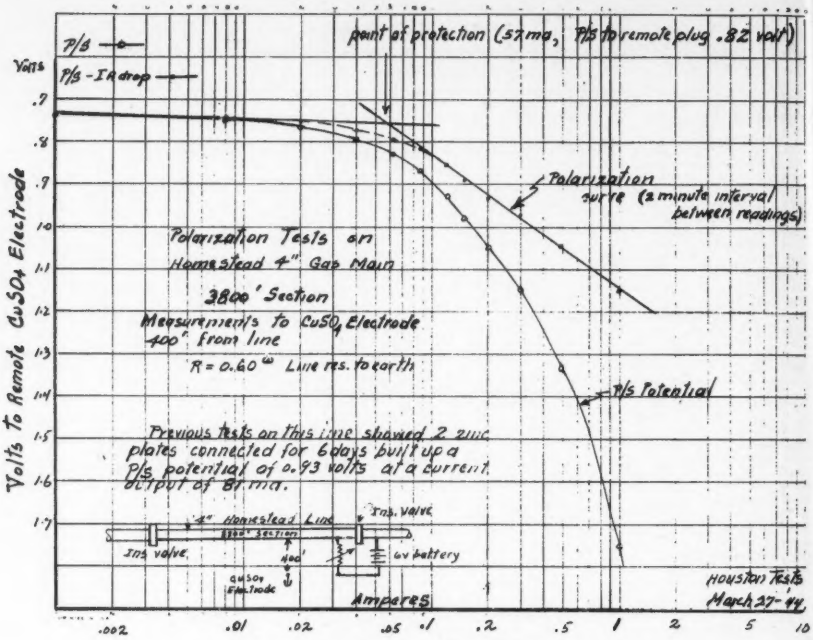


Figure 9. Results of polarization tests.

measured with ac, but are satisfactory for comparative purposes and are conveniently obtained. Table X shows a comparison of the resistances of these plates as measured by the above dc method with values obtained with 60-cycle alternating current.

Detailed measurements on these special test plates are presented on Table XI. By making measurements at intervals of two or three weeks over an extended period of time, an accurate record of the current out-

TABLE XII

Division of Current Among the Plates in a Vertical Stack of 5 Zinc Plates Connected to an Unpolarized Pipe—Houston Tests

Plate No.	STACK NO. 1			STACK NO. 2		
	Ma	Voc	Ohms	Ma	Voc	Ohms
1 Top	84	.27	3.2	73	.30	4.1
2	62	.21	3.4	62	.26	4.2
3	74	.22	3.0	68	.25	3.7
4	82	.22	2.7	74	.25	3.4
5	90	.29	3.2	83	.31	3.7
Group 1—5	400	.48	1.2	363	.467	1.28
Depth of 3½ inch Boring	18 feet			18 feet		
Resistivity of Backfill	110 ohm/cm			250 ohm/cm		
Average Soil Resistivity	600 ohm/cm			600 ohm/cm		
Calc. Res. of Group*	1.2 ohms			1.2 ohms		

* From Fig. 11, using 3½ inch for diameter and correcting for 0.1 ohm in leads and pipe, and 600ᵒ soil resistivity.

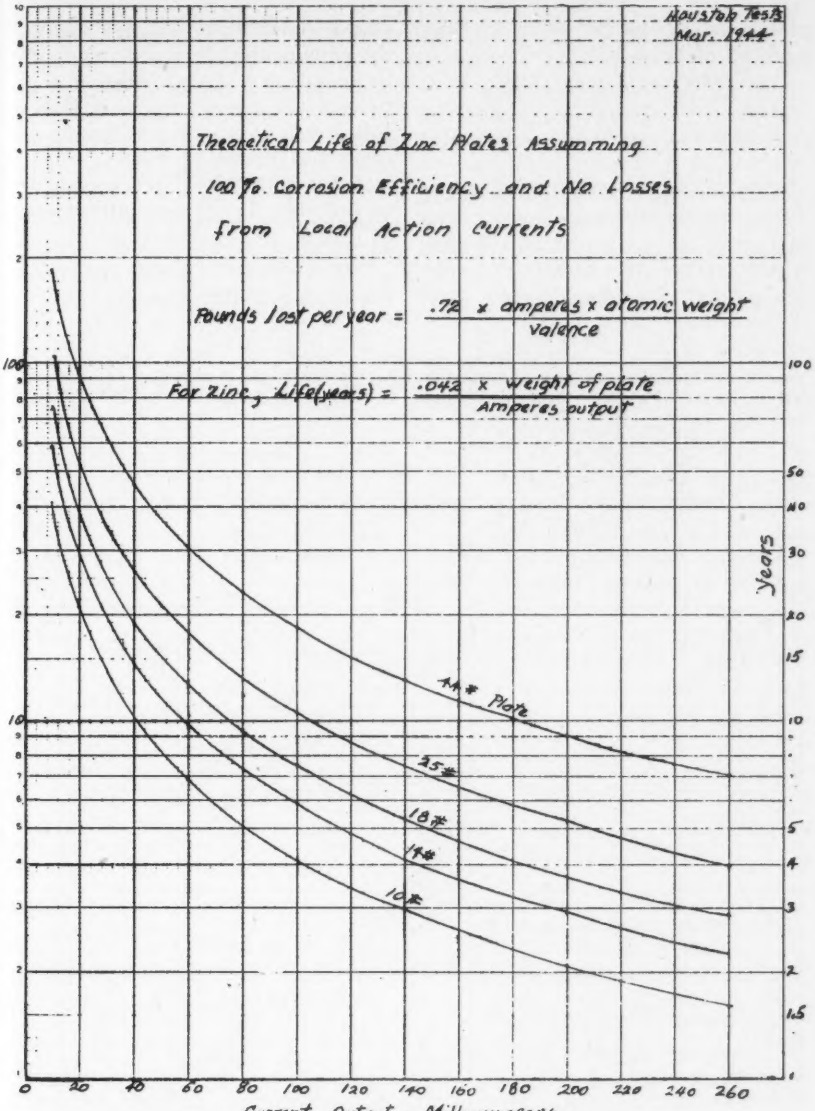

Houston Tests
Mar. 1944
Theoretical Life of Zinc Plates Assuming
100 % Corrosion Efficiency and No Losses
from Local Action Currents
Pounds lost per year = .72 x amperes x atomic weight / valence
For Zinc, Life(years) = .042 x Weight of plate / Amperes output
Years
44 # Plate
35 #
18 #
14 #
10 #
0 20 40 60 80 100 120 140 160 180 200 220 240 260
Current Output – Milliamperes

Figure 10. Curves for theoretical life of zinc plates.

put will be secured. This will permit an accurate determination of the weight loss per ampere when the rods are excavated.

The zinc plates used in the Houston installations are rolled zinc

plates having the following average analysis of impurities:

Element	*Percent*
Lead	0.08
Iron	0.008
Copper	0.004
	0.092

This corresponds with an average purity of 99.91 percent zinc. The plates are received without pigtails, which are installed locally and consist of No. 12 rubber-covered wire, sweat-soldered into a hole drilled on the edge of the plate and two inches from one end. To prevent segragation of the plate from exposure to soil strata of varying resistance or other conditions tending to concentrate current at local areas, one edge of the plate is covered with a strip of primer and coal tar pipe enamel.

From Figure 10 the theoretical life of one of these 14-pound plates

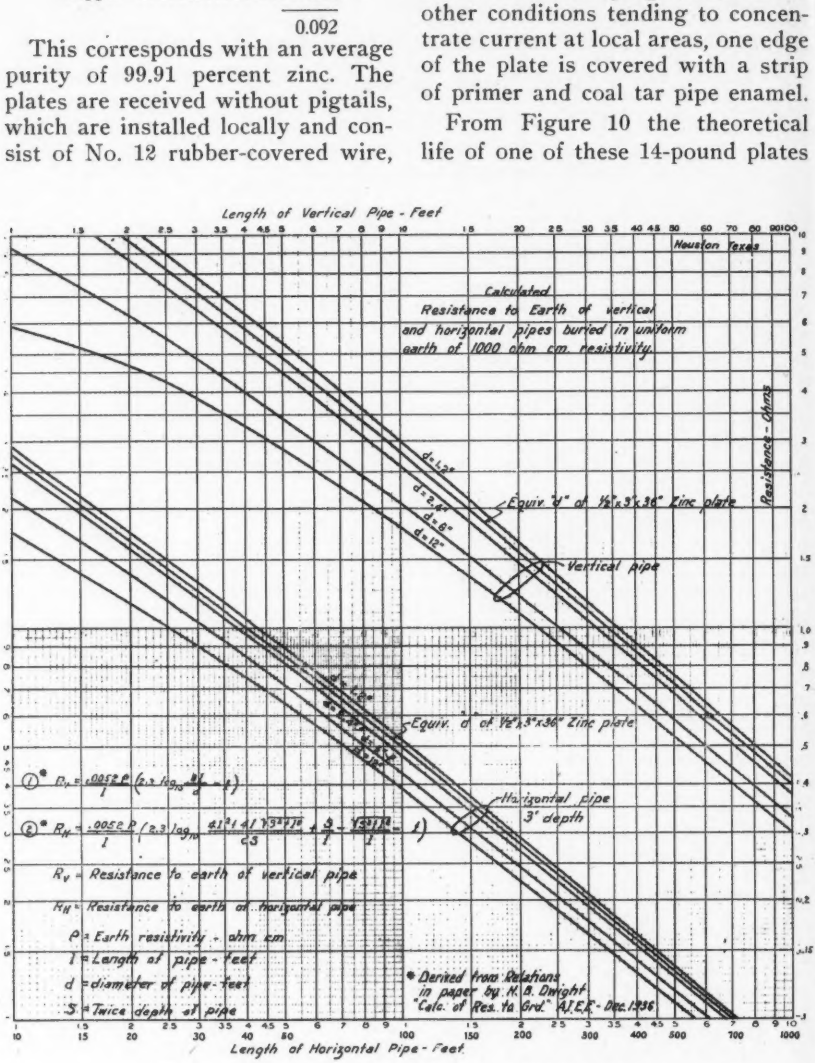

Length of Vertical Pipe - Feet
Houston Texas
Calculated
Resistance to Earth of vertical
and horizontal pipes buried in uniform
earth of 1000 ohm cm. resistivity
Resistance - ohms
d=1.2"
d=2.4"
d=8"
d=12"
Equiv "d" of ½"x3"x36" Zinc plate
Vertical pipe
Equiv. "d" of ½"x3"x36" Zinc plate
Horizontal pipe
3' depth
① * $R_v = \frac{.0052\,\rho}{l}\left(2.3\log_{10}\frac{4l}{d} - 1\right)$
② * $R_H = \frac{.0052\,\rho}{l}\left(2.3\log_{10}\frac{4l^2}{cs}\sqrt{1+\frac{s}{l}} - \sqrt{1+\frac{s}{l}} + 1\right)$
R_v = Resistance to earth of vertical pipe
R_H = Resistance to earth of horizontal pipe
ρ = Earth resistivity - ohm cm
l = Length of pipe - feet
d = diameter of pipe - feet
s = Twice depth of pipe
* Derived from Relations
in paper by H. B. Dwight
"Calc. of Res. to Grd." A.I.E.E. - Dec. 1936
Length of Horizontal Pipe - Feet

Figure 11. Resistance-to-earth curves, calculated values.

is about twenty years at a current output of 30 milliamperes. It is expected that a fairly accurate estimate of the life of the zinc under the operating conditions can be made when reliable weight loss data are available.

The data presented on Figure 9 illustrate the small magnitude of the currents required for portection of a well-coated line which is metallically insulated from other structures, and the ease with which protective potentials are secured with small amounts of zinc. A 3800-foot section of 4-inch gas main was insulated at each end and measurements were made of the resistance to earth of this section, which was found to be 0.75 ohms. This corresponds with a coating resistance of 3400 ohms per square foot. The pipe was laid 9 years ago next to a drainage ditch in 500 ohm/cm soil which is usually saturated with water. Two zinc plates, laid horizontally at the bottom of a bell hole and connected to the main, delivered a current of 81 milliamperes and changed the potential over a 6-day period from 0.7 to 0.93 volt to a $CuSO_4$ electrode. The zinc plates were then disconnected and a few days were allowed the pipe to return to its initial potential. Readings were then taken of the P/S potential measured to a remote (400-foot) ground as the current was varied from zero to a value well beyond the protective point indicated by the tests with zinc. The polarization curve was derived by subtracting the total IR drop (resistance-to-earth of pipe times current) from the pipe-to-soil potential. The break in the curve occurred at 57 milliamperes, at which point the P/S potential was 0.82 volt. Later the insulated section was extended to include 2½ miles of pipe and two vertical stacks of zinc of 5 plates gave rise to potentials above 0.9 volt over the 2½-mile section.

The writer wishes to acknowledge thankfully the valuable assistance of Mr. K. H. Logan in the conduct of the Colorado tests, and the coöperation of Mr. C. B. Abbot of the Colorado Interstate Gas Co. and Mr. G. R. Olson of the United Gas Pipe Line Co. in arranging for the tests. The writer is also indebted to the following for their coöperation in these studies: Messrs. C. L. Morgan, H. M. Fanett, M. C. Miller, O. C. Mudd, Walter Rogers, and R. A. Brannon.

References

1. Cathodic Protection or Electric Drainage of Bare Pipe Lines. G. I. Rhodes. American Gas Association Proceedings, 1935.
2. Zinc for Cathodic Protection of Pipe. Wm. Thompson Smith and Thomas C. Marshall. Gas Age, Aug. 17, 1939.
3. Experiences With Zinc Anodes. O. C. Mudd. Before the Petroleum Industries Electrical Association Annual Meeting, Houston, Texas, May 5-6, 1943.
4. A Practical Application of Zinc Anode Protection to an 18" Pipe Line. C. L. Brockschmidt. Before the Cathodic Section, Petroleum Industry Electrical Association at Kansas City, Mo., Jan. 16, 1942.
5. Progress Report on the Behavior of Zinc-Iron Couples in Soil. Melvin Romanoff. Corrosion 1, No. 2, 95, (1945) June. (This reference added by Ed.)

Corrosion Resistant Sucker Rods

TWO INTERESTING experiments dealing with corrosion-resistant sucker rod materials have been conducted by oil companies in West Texas. One of the materials consisted of nickel-plated sucker rods. The plating was applied over the standard SAE 4620 composition, which is widely used for sucker rods in corrosive wells.

After about six years' exposure these nickel-plated rods were examined and it was found that the 0.006-inch thickness of nickel had not been perforated and the rods were apparently in excellent condition. These rods were in a string with a special alloy rod more corrosion resistant than the normal 4620, and it is interesting to note that the special alloy rods in this string failed after about three years' exposure.

The thought naturally arose that if the nickel plating were once penetrated, strong galvanic effects would take place. Some of the nickel-plated rods in the corrosive brine wells of Arkansas rubbed against the tubing with the result that the coating was perforated. There was no indication of undercutting or of intense galvanic effects. This is brought out in Figure 1. The absence of the galvanic corrosion is assumed to be due to the absence of oxygen. In the absence of oxygen and under the acid conditions existing, the normal corrosion rate apparently proceeded with some difficulty and there is not enough depolarizing agent present to permit accelerated attack.

In the second experiment, the sucker rod string and coupling were made from a hardenable form of nickel-copper alloy. This alloy contains approximately two-thirds nickel, one-third copper and an addition of about five percent of aluminum, so that there is a phase formed which precipitates upon heat treatment of the alloy. Tensile strengths of the order of 125,000 to 140,000 pounds per square inch are obtained, with elongation in excess of twenty percent. This string of sucker rods, after about four years of service in a very corrosive well in West Texas, has shown no indications of deterioration.

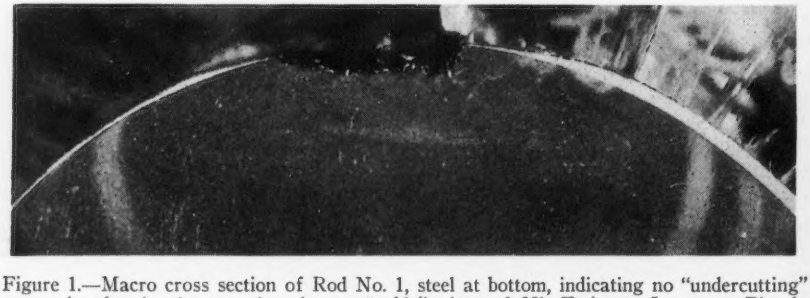


Figure 1.—Macro cross section of Rod No. 1, steel at bottom, indicating no "undercutting" as result of galvanic corrosion due to "noble" plate of Ni. Etchant: 5 percent Picral; Mag. x 8.

Corrosion of 18-8 Alloy Furnace Tubes in High-Temperature Vapor Phase Cracking Service

By E. Q. Camp and Cecil Phillips
Technical and Research Division, Humble Oil & Refining Company
and
Lewis Gross
Process Division, Taylor Refining Company

FURNACE tubes of 18-8 type stainless steels have been used successfully for many years in the petroleum industry in high-temperature cracking operations, although these tubes are exposed to severely corrosive environments on both the fire side and the hydrocarbon side. Because of the excellent corrosion resistance of the 18-8 type stainless steels, many furnace tubes of this alloy are still in service after 100,000 hours of operation in conventional cracking plants. This paper presents a discussion of a unique case of severe hydrocarbon-side corrosion of 18-8 alloy furnace tubes in which failures were experienced after only 120 hours of operation. This corrosion occurred in a superheater furnace in which a 200° to 400° F. boiling range naphtha was cracked in vapor phase for the production of butadiene.

Operating Data

The true vapor phase process is employed in reforming 200° to 400° F. boiling range naphtha at a temperature of 1310° to 1325° F. for the production of butadiene. This process was adapted for this purpose as a part of the governmental program that was put into effect to meet the demand for the production of butadiene required in making synthetic rubber. Three plants of this type were constructed by Defense Plant Corporation for operation under contract with Rubber Reserve Company. One of these plants is operated by Taylor Refining Company, Corpus Christi, Texas. In the initial operation of this plant, a peculiar and acute type of corrosion was experienced which resulted in the failure of the Type 304, 18-8 alloy tubes in the naphtha circuit of the superheater furnaces after only 120 hours of operation. Similar corrosion was experienced at the other two plants. One of these plants is in operation at present, and the other was converted into a unit for the production of gasoline after several months of intermittent operation during which attempts to develop methods of suppressing the corrosion were unsuccessful. It is believed that the type and degree of corrosion experienced at these plants are without parallel.

This paper presents the results obtained in this investigation which was conducted for the purpose of determining the cause of the corrosion and of developing the most feasible method of reducing the corrosion to a minimum.

Plant Operation

A flow diagram of the true vapor phase process as it is employed in the production of butadiene is shown in Figure 1. The fresh feed to the plant operated by Taylor Refining Company amounts to approximately 2,000 barrels per day with both superheaters in operation. Most of the fresh feed is pumped directly into

the furnace feed accumulator. Approximately 400 barrels per day enters the top of the absorber in which it flows countercurrently to the effluent by-product gas. This naphtha is withdrawn as a side stream and flows into the furnace feed accumulator. In addition to the fresh feed, the furnace charge contains approximately 400 barrels per day of aromatic distillate (from side stream stripper on fractionator) and about 750 barrels per day of debutanizer bottoms. The combined feed is charged to a preheater that is operated with an outlet temperature of approximately 950° F. The charge is then heated in two superheaters (operated in parallel) to a temperature of approximately 1325° F. which is slightly below the optimum temperature required for the reaction. The vaporized naphtha is mixed with a recycle gas (depropanizer overhead) that has been heated in separate sections of the furnaces to a temperature of approximately 1440° F. The resulting mixture is passed into a reaction chamber and is then quenched to a temperature of 400° to 450° F. with bottoms from the fractionator. The reactor product stream flows into the fractionator. From this point the operation of the equipment (fractionator, absorber, depropanizer, and debutanizer) is conventional.

The recycle gas is the overhead from the depropanizer and amounts to about 150,000 cubic feet per hour. This gas consists of approximately 65 mole percent of propane and propylene and 25 mole percent of ethane and ethylene, the remainder

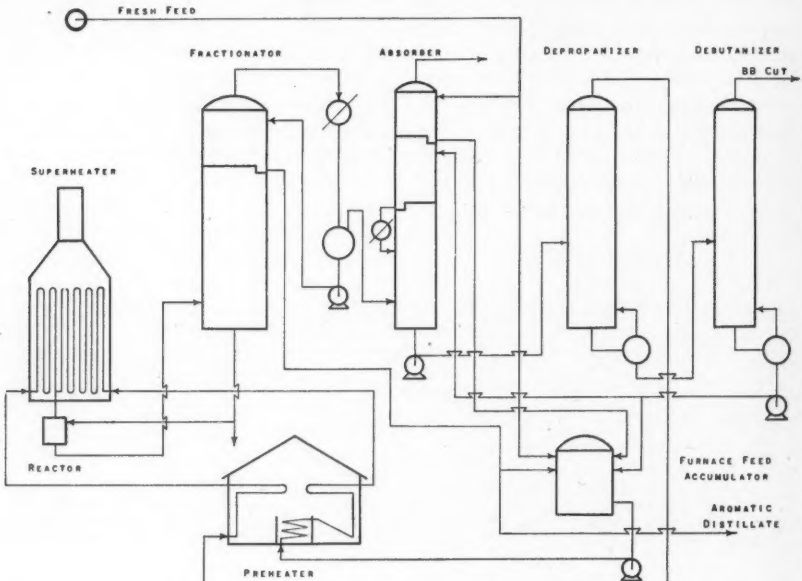


Figure 1. Flow diagram of butadiene plant operated by Taylor Refining Company.

being hydrogen, methane, butane, and butylenes.

Furnace Operation

The combined naphtha feed and the recycle gas are charged in separate circuits to a single preheater furnace. The naphtha and recycle gas leave the preheater at temperatures of approximately 950° F. and 700° F., respectively, and flow separately through each of two superheater furnaces operated in parallel. Each superheater furnace contains 108 vertical tubes, 27 feet in length with an outside diameter of 2⅜ inches and a wall thickness of 0.156 inch. The naphtha and recycle gas circuits contain nine parallel passes each. Each naphtha pass and each gas pass contains eight and four tubes, respectively. All the tubes are of Type 304 stainless steel (18 percent chromium, 8 percent nickel), except for the first two tubes in each pass of the naphtha circuit which are of 4 to 6 percent chromium steel. Each furnace is fired with twelve 18-inch burners arranged in a circle (approximately 8.75 feet in diameter). The burners are set at a 30-degree angle with the horizontal floor and are sloped toward the burner circle to give the flame a whirling motion. The air to the burners is heated to about 600° F. in convection heaters on top of the superheaters. In addition, the burner aspirators draw in approximately 10 percent of cold air.

The naphtha and recycle gas from the preheater enter the superheaters through separate distributing rings at a pressure of approximately 110 pounds per square inch. Each stream is admitted to the superheater furnace tubes through critical velocity orifices (approximately 0.5 inch in diameter). The inlet pressure for each superheater pass is approximately 30 to 40 pounds per square inch with an outlet pressure of about 20 pounds per square inch. The outlet temperature of the naphtha and recycle gas are approximately 1325° F. and 1440° F., respectively. The vapor velocity through the naphtha tubes varies from 80 feet per second at the inlet to 320 feet per second at the outlet. The two streams are combined at the outlets from the superheaters and are mixed in the reactors (capacity of each is 3.6 cubic feet). The product streams from the reactors are quenched to a temperature of 400° to 450° F. with bottoms from the fractionator, and then are allowed to flow into the fractionator.

Corrosion of Superheater Furnace Tubes

In the initial stages of processing naphtha from Refugio crude at the plant operated by Taylor Refining Company for the production of butadiene, the plant was rendered inoperable because of rapid corrosion of the 18-8 alloy tubes in the naphtha circuit of the superheater furnaces. This corrosion resulted in the failure of the tubes (particularly those near the outlet, i.e., the seventh and eighth passes in from) 120 to 400 hours of operation. Examination of a number of tubes from the superheater furnaces indicated that the failures were due primarily to uniform thinning of the tube walls; however, severe pitting did occur, particularly in the tubes near the inlets to the superheaters and in new tubes in the outlet passes when they were first put into operation.

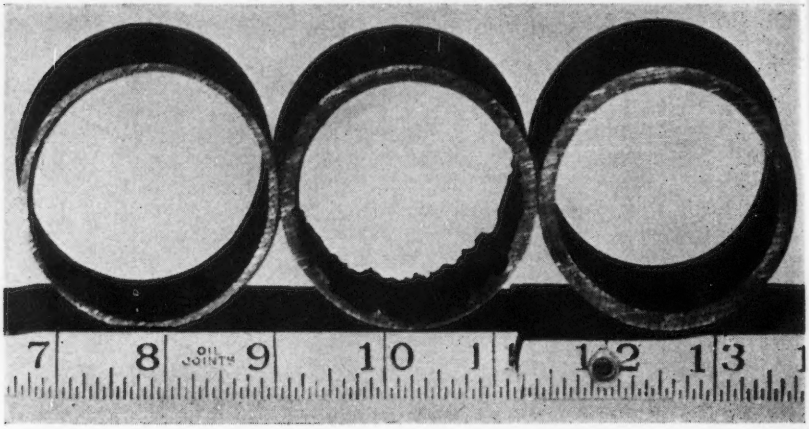


Figure 2. Examples of uniformly thinned, pitted and new 18-8 alloy superheater furnace tubes.

Figure 2 shows examples of both the general thinning and the pitting type of corrosion experienced, and a section of a new tube. Figure 3 shows a section cut longitudinally through one of the tubes which had undergone severe pitting. It will be observed that one side is severely pitted while the other is only slightly attacked. The corrosion was limited primarily to the center sections of the tubes and was more severe on the side (internal surface) next to the burners. The end sections (four to six feet) and the return bends were relatively free of corrosion. This indicates that metal temperature is an important factor in the corrosion.

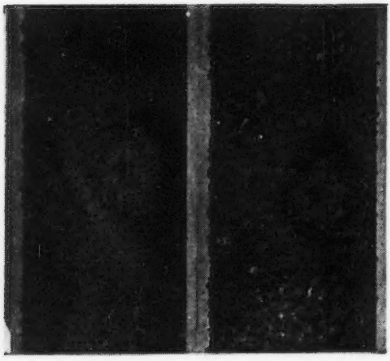


Figure 3. Internal surface of 18-8 alloy superheater furnace tube showing severe pitting on side facing fire.

The results of a number of metallurgical examinations of sections of tubes from Taylor's butadiene plant and, for comparison, from Lion's plant in which no severe corrosion was experienced initially, showed that the furnace tubes from both plants were rather severely carburized. It is generally known that carburized 18-8 alloy is susceptible to corrosion, particularly intergranular and perhaps uniform surface attack, even under mildly corrosive conditions. The furnace tubes that were examined from these two plants were of identical metal (Type 304 stainless steel), were carburized to about the same extent, and were operated under comparable conditions with respect to temperature,

TABLE I

Comparison of Analytical Data

TESTS	LION OIL REFINING CO.					TAYLOR REFINING COMPANY*						
	Fresh Feed	Aromatic Distillate	Detutanizer Bottoms	Flash Drum O.H.	Flash Drum Btms.	Fresh Feed	Aromatic Distillate	Debutanizer Bottoms	Combined Feed	Flash Drum Bottoms	Water From Absorber Bottoms	Water From Absorber Side Cooler
Gravity, °API	61.6	40.8	51.4	55.4	19.6	49.4	37.2	47.0	43.6	....	....	....
I. B. P., °F	122	179	128	119	170	242	215	113	129	....	....	....
F. B. P., °F	393	355	367	411	....	392	360	396	385	....	....	....
Recovery, percent	98.0	98.0	98.0	98.0	....	98.0	98.0	95.0	96.0	....	....	....
Residue, percent	0.7	1.0	1.0	1.0	....	1.0	1.0	1.0	1.0	....	....	....
Loss, percent	1.3	1.0	1.0	1.0	....	1.9	1.0	4.0	3.0	....	....	....
5 percent off at, °F	154	209	138	144	....	279	240	143	179	....	....	....
50 percent	247	247	176	220	....	321	280	221	291	....	....	....
95 percent	362	327	343	364	....	367	336	394	385	....	....	....
Doctor Test	DNPED	Pass	DNP	DNPED	....	Pass	Pass	Pass	Pass	....	....	....
Copper Strip Corrosion	DNP	Pass	Pass	Pass	....	Pass	Pass	Pass	Pass	....	....	....
Copper Dish Gum	5.7	80.2	107.3	34.6	....	2.7	102	154	121	....	....	....
Neutralization Value	0.017	0.021	0.021	0.014	0.063	0.024	0.024	0.028	0.021	0.028-0.042	....	....
Lamp Sulfur	0.018	0.018	0.024	0.019	....	0.014-0.010	0.021-0.019	0.012-0.015	0.025-0.026	....	....	....
Mercury Number	3.5-3	2.5	0.0	0.0	....	3.5-3.0	3.0-2.0	3.5-4.0	2.0-1.0	....	....	....
Copper Number	3-4	0.0	2.0	1.5	....	0.0	0.0	0.0	0.0	....	....	....
Ester Number	2.6	5.1	1.9	2.0	....	2.1	3.6	2.0	3.5	....	....	....
Peroxide Number	0.1-0	1.8	0.3	0.3	....	1.5-2.7	3.6	2.9	5.5	....	....	....
Hydrogen Sulfide, Qual.	None	None	None	Trace	None	None	None	None	None	....	....	....
Salt Content, Lb./1,000 bbl	None	None	None	Trace	12.8	None	None	None	None	2.5	....	....
Dissolved O_2, Mg./Liter	24.4‡	....	....	....	....	55	....	....	....	....	....	....
H_2S Evolved at 1300° F., Lb./M. bbl.	14.1	....	....	8.7	....	2.1	....	....	1.3	....	....	....
Chlorides, p.p.m.	....	....	....	....	....	....	....	....	....	....	49.7	21.3
Sulfates, p.p.m.	....	....	....	....	....	....	....	....	....	....	25	15
Sulfites, p.p.m.	....	....	....	....	....	....	....	....	....	....	None	None
Sulfides, p.p.m.	....	....	....	....	....	....	....	....	....	....	None	None
Organic Acids (as Acetic), p.p.m.	....	....	....	....	....	....	....	....	....	....	1,580†	340
Iron, p.p.m.	....	....	....	....	....	....	....	....	....	....	959	37
Total Sulfur, p.p.m.	....	....	....	....	....	....	....	....	....	....	8.4	5.4

* Charging Refugio naphtha. This naphtha has stood in tankage for several months.
† No organic acids were found in comparable streams from Lion's butadiene plant.
‡ Fresh feed to naphtha preheater.

pressure, rate of firing, etc. Since severe corrosion was experienced at Taylor's plant in comparison with that experienced originally at Lion's plant, it was thought that the tube failures at Taylor's plant were due to the presence of corrosive constituents in the naphtha charged to the plant.

Analytical Examination of Naphtha Samples

Early in the investigation of this corrosion problem extensive analytical data were obtained on comparable sets of naphtha samples from Taylor's plant and from Lion's plant. The results obtained are presented in Table I. These data are not conclusive as to the cause of the corrosion experienced at Taylor's plant. In the initial stages of this investigation it was believed that the presence of organic acids in water from the absorber at Taylor's plant was a significant factor in the corrosion of the furnace tubes. The absence of organic acids in a comparable sample from Lion's plant supported this conclusion. It was postulated that dissolved oxygen in the fresh feed resulted in the formation of organic acids in the cracking step and that these acids were the cause of the corrosion of the furnace tubes. However, a later plant run in which the fresh feed was maintained free of dissolved oxygen by gas blanketing the naphtha immediately after distillation disproved this assumption, since no apparent decrease in the corrosiveness of the naphtha was observed. Laboratory corrosion tests not only substantiated the plant run on gas blanketed Refugio naphtha but also showed that the presence of organic acids in the naphtha inhibited rather than accelerated the corrosion. A comparison of the data in the table indicates that probably the most significant difference in the charge stocks to the two plants is that the fresh feed and combined feed to Lion's plant contain mercaptan sulfur, whereas comparable streams to Taylor's plant are free of mercaptan sulfur. Hydrogen sulfide evolution tests at 1300° F. on the combined feed to Taylor's plant and Lion's plant gave 1.3 and 8.7 pounds of hydrogen sulfide per 1,000 barrels of oil, respectively. Similar tests on the fresh feed to these two plants gave 2.1 and 14.1 pounds of hydrogen sulfide per 1,000 barrels of oil, respectively. These data do not show the cause of the corrosion experienced at Taylor's plant, but they indicate that corrosion at this plant may occur because of the absence of certain sulfur compounds, such as mercaptans, in the combined feed. The basis for this conclusion is, as will be shown later in this paper, that sulfur (as mercaptans, carbon disulfide, free sulfur, etc.) is an excellent inhibitor for the type of corrosion experienced at Taylor's plant as well as for that experienced in other plants employing this process.

Laboratory Studies

Since it was not possible to determine the cause of the corrosion experienced at Taylor's butadiene plant by analyzing the charge stocks and recycle streams, bench scale laboratory studies were conducted (under conditions approximating those existing in the plant) for the purpose of developing the most feasible method of minimizing the corrosion.

The equipment employed in the laboratory investigation is shown in Figure 4. The various naphthas were cracked in a quartz tube (0.875 inch inside diameter) at essentially atmospheric pressure and at temperatures comparable to those employed in plant practice. A naphtha charge rate of 200 cc. per hour was used in these tests. The temperatures were measured with a thermocouple placed against the outside of the quartz tube in the center of the end section of the furnace. Three 18-8 alloy test specimens (cut from a furnace tube from Taylor's butadiene plant) were placed end-to-end in the quartz tube at the center of the outlet section of the furnace. The location of the metal test specimens is shown in Figure 4. The test periods varied in length, but most of the runs were in progress for 20 hours. The corrosion rates were calculated by the conventional weight-loss method.

The results obtained in tests that were made for the purpose of reproducing the corrosion experienced at Taylor's plant are shown in Figure 5. These results indicate that naphtha from Refugio crude is extremely corrosive to 18-8 alloy under the conditions of the laboratory tests; however, the corrosion rates obtained in the laboratory are not as high as those experienced in the plant. This difference is probably a function of the velocities employed. The velocity of the naphtha vapors in the laboratory tests was extremely low, whereas high velocities (approximately 200 feet per second) were employed in plant operation. Maximum corrosion rates occurred at 1400° to 1450° F. Less corrosion

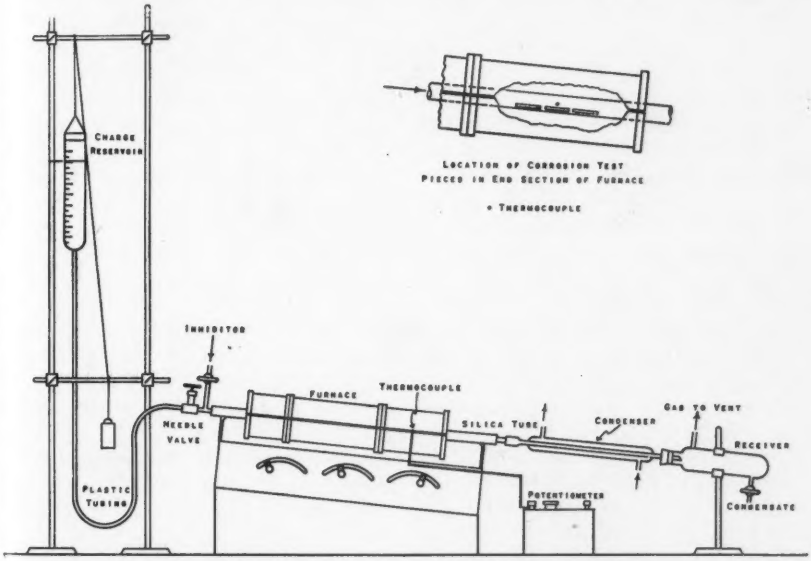


Figure 4. Apparatus used in corrosion tests.

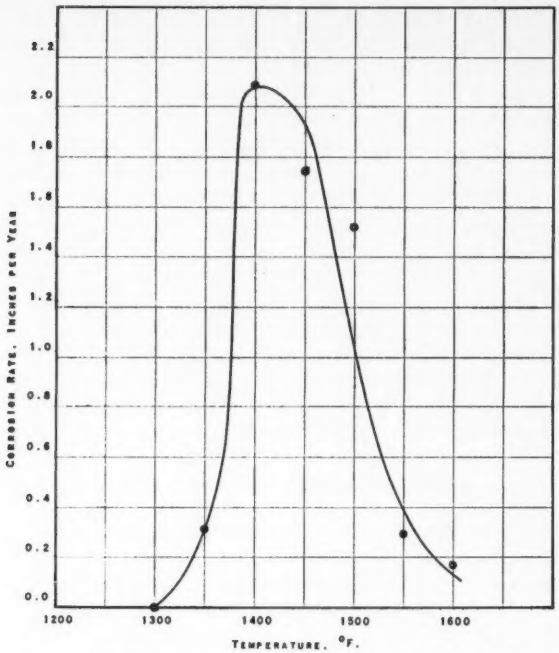


Figure 5. Corrosion rates of 304-type stainless steel by Refugio naphtha.

was obtained at higher and lower temperatures. It is not known whether there is a reduction in the tendency for the naphtha to corrode at the higher temperatures or whether the deposition of coke at these temperatures is such that the metals are shielded from corrosion.

A series of laboratory tests was made to determine the effect of various sulfur compounds on the tendency of Refugio naphtha to corrode 18-8 alloy in the temperature range of 1300° to 1500° F. The results of the tests in which free sulfur was added to the naphtha are shown in Figure 6. Results obtained using similar concentrations of sulfur as butyl mercaptan and carbon disulfide were comparable to those obtained with free sulfur. The addition of 0.05 to 0.5 percent by weight of sulfur (as free sulfur, butyl mercaptan, or carbon disulfide) to the naphtha essentially eliminates its tendency to corrode 18-8 alloy. It is indicated that lower amounts of sulfur effect marked reductions in the corrosion, but more uniformly consistent results were obtained on adding 0.05 percent by weight and higher of sulfur. It was observed also that the addition of sulfur essentially eliminated coke deposition on the 18-8 alloy. Both of these observations have been confirmed by the results obtained in plant operation.

The effect of the addition of small amounts of distilled water on the tendency of the naphtha to corrode 18-8 alloy under cracking conditions is shown in Figure 7. These data indicate that the corrosion can be eliminated by adding 0.06 to 0.4 percent by weight of water to the naphtha. Larger amounts of water are not detrimental, but are unnecessary. It was observed that the addition of water also effected a marked reduction in the tendency of the naphtha to coke 18-8 alloy under the test conditions employed. No plant experience is available to substantiate these results.

Further tests in the equipment previously described indicated that carbon dioxide, ethyl alcohol, acetic acid, hydrogen sulfide, and sulfur dioxide are satisfactory inhibitors for controlling the type of corrosion experienced at Taylor's butadiene plant. The optimum quantities of these materials required to maintain corrosion and coke deposition at a minimum were not established because sulfur and water had been found to be adequate for this purpose.

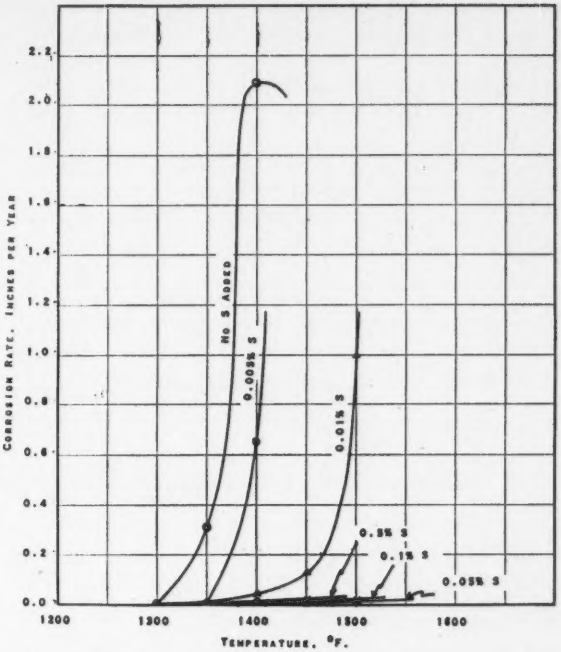


Figure 6. Effect of sulfur on corrosion of 304-type stainless steel by Refugio naphtha.

Several exploratory corrosion tests were made in attempts to establish the cause of the corrosion; however none of these tests gave an indication as to the causative agent. It was shown that the removal of active sulfur compounds, peroxides, chlorides, and inorganic salts (by refluxing with molten metallic sodium followed by washing with distilled water and filtering) effected no reduction in the tendency of the naphtha to corrode 18-8 alloy. The addition of such compounds as benzoyl peroxide, magnesium chloride, acetylene, isobutylene, normal butane, butadiene, furfural, aniline, etc., to a noncorrosive naphtha (normal hexane) failed to induce corrosion under the cracking conditions employed. Various types of essentially pure hydrocarbons, such as paraffins, aromatics, naphthenes, and unsaturates, were found to be noncorrosive.

The results of corrosion tests in which oxygen was excluded from the naphtha from Refugio crude indicate that dissolved oxygen is not a significant factor in the corrosion experienced at Taylor's butadiene plant.

Plant Runs

In order to evaluate the possible effect of charge stock on the corrosion of the 18-8 alloy furnace tubes, a trial run was made at Taylor's butadiene plant employing a highly paraffinic naphtha (normal hexane)

as fresh feed. This run was in progress for approximately 700 hours without any evidence of corrosion of the superheater furnace tubes. Samples of various naphtha streams were taken for analytical examination during this run. The results obtained on analyzing these samples were not materially different from those obtained on comparable samples when processing Refugio naphtha and are not conclusive as to the cause of the corrosion when processing Refugio naphtha, or to the lack of corrosion when charging normal hexane.

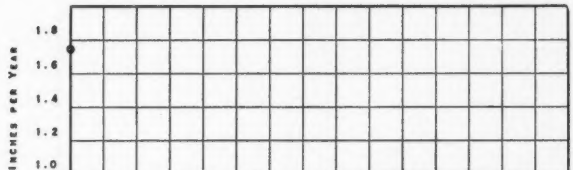


Figure 7. Effect of distilled water on corrosion of 304-type stainless steel by Refugio naphtha at 1450 degrees Fahr.

When the trial run on normal hexane was terminated, a run was made on freshly distilled, gas-blanketed Refugio naphtha to which sufficient butyl mercaptan was added to maintain 0.005 to 0.006 percent by weight of sulfur (as butyl mercaptan) in the furnace charge. This run was terminated after 118 hours because of the failure of the eighth tube in a naphtha pass. The results obtained on inspecting the furnace tubes were not as discouraging as the short length of the run indicated. The seventh and eighth tubes were severely attacked, whereas only incipient corrosion had occurred on the sixth tube. In previous runs that were terminated in about the same length of time because of tube failures, it was found that the fifth, sixth, seventh, and eighth tubes were corroded to about the same extent with only 0.01 to 0.02 inch of the original 0.156 inch wall thickness remaining.

Because of the results obtained in the first run employing sulfur as an inhibitor and because the laboratory results indicated that sulfur in concentrations up to 0.5 percent by weight was beneficial rather than harmful to the 18-8 alloy, a second run was made employing a minimum of 0.05 percent of added sulfur based on the furnace charge. An inspection of the furnace tubes after 135 hours of operation showed that no corrosion had occurred in any of the tubes. As a result of this successful run, operation of the unit was continued. Carbon disulfide is being injected in a quantity sufficient to maintain approximately 0.3 percent by weight of sulfur (as carbon disulfide) in the furnace feed. The unit now has been in operation for 6,000 hours without any evidence of corrosion in the naphtha tubes of the superheater furnaces. After 2,764

hours of operation with sulfur injection, a failure occurred in one of the outlet tubes of the recycle gas circuit. On inspection, the failure was found to be due to pitting at random in the gas tube. Only one other outlet gas tube was found to be pitted sufficiently to require replacement. None of the other tubes in the recycle gas circuit was attacked. For several weeks prior to the failure of the gas tube, the concentration of hydrogen sulfide in the recycle gas stream was subject to considerable variation. A large quantity of absorber overhead gas had been used for recycle gas which resulted in a substantially lower concentration of hydrogen sulfide in the recycle gas stream. It is thought that this lower hydrogen sulfide content was a contributing factor in the corrosion of the gas tubes.

The addition of sulfur to the furnace feed has essentially eliminated coke deposition in the furnace tubes. With added sulfur in the charge, only a very thin, hard scale formed on the inside of the tubes. Analysis of this scale showed it to be essentially carbon. Table II presents a comparison of the chemical composition of scales removed from the superheater furnace tubes before and after sulfur was added to the charge stock.

Summary

The results of laboratory investigations indicate that the corrosion experienced in the 18-8 alloy tubes in the naphtha circuit of the superheater furnaces at Taylor's butadiene plant can be eliminated by adding either 0.05 to 0.5 percent by weight of sulfur (as free sulfur, carbon disulfide, butyl mercaptan, etc.) or a minimum of 0.06 to 0.4 percent by weight of water to the naphtha charge. Carbon dioxide, ethyl alcohol, and acetic acid are also satisfactory inhibitors for suppressing this type of corrosion, but their value as inhibitors is not as well established as that of sulfur compounds and water.

Satisfactory operation is being obtained at Taylor's butadiene plant by adding sufficient carbon disulfide to the fresh feed to maintain approximately 0.3 percent by weight of sulfur (as carbon disulfide) in the furnace charge. No measurable corrosion has occurred in any of the tubes in the naphtha circuit of the superheated furnaces after over 6,000 hours of operation with carbon disulfide injection. In addition, the injection of carbon disulfide has essentially eliminated coking difficulties in the superheater furnace tubes.

Extensive work was carried out for the purpose of defining the corrosion experienced at Taylor's butadiene plant, but the cause of the corrosion is not apparent from any of the results that were obtained. The available data do indicate, however, that the corrosion is not due to the presence of chlorides, salts, sulfur, dissolved oxygen, oxygen bearing compounds, or to any

TABLE II

Composition of Scales from Superheater Furnace Tubes

Constituent	Scale Formed Before Sulfur Was Added to Charge Stock, %	Scale Formed After Sulfur Was Added to Charge Stock, %
Carbon	91.60	96.00
Nickel	1.63	None
Chromium	1.26	Trace
Iron	2.34	2.20
Sulfur	None	None
Silicon	None	...
Ash	6.00	3.13

one specific type of hydrocarbon (such as paraffins, naphthenes, aromatics, or unsaturates) in the naphtha feed.

Acknowledgments

The investigation of this problem was conducted at the request of Petroleum Administration for War. The program in general was under the direction of the Technical Advisory Committee with Dr. H. D. Wilde, Manager of the Refining Technical and Research Division, Humble Oil & Refining Company, as coördinator. The investigation was conducted in the Baytown Laboratories, Technical and Research Division, Humble Oil & Refining Company, Baytown, Texas, with the assistance of Mr. D. C. Walsh and Mr. P. S. Viles. The authors wish to acknowledge the helpful suggestions and advice of Dr. B. F. Armendt and Dr. Sherman S. Shaffer of Humble Oil & Refining Company, of Mr. J. L. Sewell of Taylor Refining Company, and of Lt. Col. M. C. Rogers and Major R. W. Pachaly of Petroleum Administration for War. Appreciation is extended to Mr. J. B. Rogerson of Lion Oil Refining Company for supplying samples and for submitting data on operations of Lion's butadiene plant. The authors are also indebted to Humble Oil & Refining Company, Taylor Refining Company, Lion Oil Refining Company, Petroleum Administration fo War, Petroleum Conversion Cor poration, The Office of Censorship, and The Office of Rubber Reserve for permission to publish the results of this investigation.

1946 N. A. C. E. Convention

May 7, 8 and 9, 1946, have been chosen by the Board of Directors as the dates on which and Kansas City, Missouri, the city in which will be held the next annual meeting and convention of the National Association of Corrosion Engineers. Official headquarters will be at the President Hotel, Kansas City, Missouri, with the principal sessions and exhibits of corrosion-prevention and mitigation materials, equipment and services scheduled for the Municipal Auditorium. Plans are being made and a program compiled which will cover phases of corrosion problems as encountered in various industries. In order to cover the scope laid out for the technical program, it is planned to schedule simultaneous sessions, and to include meetings of the various special committees at the time the regular sessions are being held.

Throughout the three days of the convention, there will be shown in the main arena of the Municipal Auditorium—adjacent to the meeting rooms—exhibits featuring the newest in corrosion-prevention equipment and materials, with technically trained men in attendance to explain and demonstrate the workings. Corrosion engineers attending the convention will not only have an opportunity to hear discussed the latest practice in materials protection, but also will have an unparalled opportunity to witness demonstrations and observe applications of the developments in the science of corrosion mitigation, prevention and control.

Analysis of Data in Cathodic Protection of An Open Condenser Box

(References for article of same title appearing on pages 70-82, June Corrosion.)

By J. J. Stadtherr

Resident Chemist, Heath Refinery, The Pure Oil Company

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1946 N.A.C.E. CONVENTION

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Corrosion Abstracts

GENERAL

Corrosion Research and Abatement—Yesterday and Today. FRANK N. SPELLER, Metallurgical Consultant. Corrosion **1,** 1 (1945) Mar.

Discusses the history and development of corrosion control as it is practiced.

Corrosion Research Project at Kure Beach Test Station. HARRY W. STEVENSON, Industrial Editor. Chem. & Eng. News Ed. **23,** 1160 (1945) July 10.

Kure Beach Test Station has been in operation for 10 years. This is a coöperative test program where resistance of metals, alloys and finishes to sea water, salt atmosphere and marine organisms are tested. Article indicates scope, complexity and usefulness of testing program.

BOILER CORROSION

External Corrosion of Furnace-Wall Tubes—I. History and Occurrence, and II. Significance of Sulfate Deposits and Sulfur Trioxide in Corrosion Mechanism. W. T. REID, Bur. of Mines, R. C. COREY and B. J. CROSS, Combustion Eng. Co., Inc. Trans. of the A. S. M. E. **67,** 279 & 289 (1945) May.

Since 1942 many large central-station boiler furnaces burning pulverized coal and removing the ash or molten slag have experienced external corrosion of furnace-wall tubes. Problem is being investigated jointly by Bureau of Mines and Combustion Engineering Company. Corrosion occurred in range of normal temperatures. Deposits are of two types, one having the appearance of a bluish white porcelain enamel, being largely soluble in water in which it produces an acid reaction, and consisting principally of sodium and potassium sulfates in a complex form. The second type is iridescent blue or black, insoluble in water, and may contain significant amounts of carbon, and consists primarily of iron sulfate. Study of deposit showed it to consist primarily of a solid solution of sodium and potassium sulfates and alkali-metal ferric trisulfates. Laboratory studies indicate the mechanism of corrosion to involve the removal of the normally protective oxide on the furnace tubes by (a) the condensation on the relatively cool tubes of alkali-metal oxides which are converted to the corresponding sulfates by the SO_3 in the furnace, and (b) the subsequent reaction of the iron oxide on the tubes and the alkali-metal sulfates with the SO_3 evolved as the result of the slagging reaction in the coal ash deposited mechanically on the "enamel." Alkali-metal ferric trisulfates result. Deslagging causes thermal decomposition of these compounds and the cycle is repeated. The above mechanism suggests that ventilation of tubes with air to reduce SO_3 concentration and decrease deposition of alkalies as remedy. Field observations bear out this prediction.

CATHODIC PROTECTION

Methods of Determining Effectiveness (of Cathodic Protection). R. B. MEARS and R. H. BROWN. Gas. **20**, No. 12, 35, 39-40, 42 (1944). C. A. **39**, 684 (1945) Feb. 20.

The following methods are discussed: 1, visual inspection; 2, gravimetric tests on coupons; 3, colorimetric tests for ions of the protected metal; 4, electrochemical methods.

Cathodic Protection Interference. A. V. SMITH. Gas. **21**, No. 1, 39-40, 43 (1945).

When two structures are located within a reasonable distance of each other and cathodic protection is to be installed on one structure, cathodic interference will undoubtedly exist to some extent on the other structure. If properly handled this interference current will in no way endanger the foreign structure. Also this interference can be used to provide some protection for the other structure. Desirable results can be secured only by the cooperation of those responsible for all of the involved structures. Methods for evaluating current flow and for correction of the effect are discussed. C. A. **39**, 895 (1945) Mar. 10.

Cathodic Protection Overcomes Operating Difficulties in Mechanical Sewage Filters. ALBERT B. KOZMA, Supt. Joint Meeting Sewage Treatment Plant, Rutherford, N. J. Water Works and Sewerage **92**, 109 (1945). Apr.

Difficulty experienced from galvanic action due to use of copper screens and steel gratings resulting in screen plugging. Cathodic protection installed employing selenium rectifier and graphite electrodes. Screens and gratings were made cathodic. Employs 3.9 amps. at 12 volts to protect the screens and gratings for 2800 sq. ft. of nominal filter area. After 4 months there was a thick soft brownish deposit noted on the unpainted steel gratings. Analysis showed no carbonate or copper in scale. Deposit was easily washed off. Copper screens were tarnished but clean. At end of one year, no scale had built up on screens and steel appeared to be in excellent condition. Cost is nominal, $15 per year (neglecting original cost) in contrast to cleaning costs previously of $1600.

Cathodic Protection of Steel Surfaces in Contact with Water, pt. 2. LEE P. SUDRABIN, Water Works & Sewerage, **92**, 51-57, (1945) Feb.

Discusses practical application of the process. Deals with sources of protective current; rectifiers; generators; evaluating protection; determining the effectiveness of cathodic protection; protection of water tanks; effect of ice and temperature; and economic considerations.

Analysis of Data in Cathodic Protection of an Open Condenser Box. J. J. STADTHERR, Pure Oil Co. Corrosion **1**, 70 (1945) June.

Cathodic protection has been applied to open box condensers with considerable success. Complete dis-

tribution of cathodic protection on each square foot of box and coil was not obtained. Favorable results were evidenced by no condenser tube failure in four years, very little corrosion on walls of box, and easily removed scale formations.

Corrosion of Steel and Its Mitigation. W. R. SCHNEIDER, Pacific Gas and Electric Co., J. Am. Water Works Assoc. **37,** 245 (1945) Mar.

Concerns the corrosion of steel pipes under water or soil. Survey methods and their interpretations are given. Advantages of electric or cathodic protection is discussed. The utility of horizontal and vertical ground beds is discussed. The various types of current sources available and general precautions in applying cathodic protection are given.

Progress Report on the Behavior of Zinc-Iron Couples in Soil. MELVIN ROMANOFF, National Bureau of Standards. Corrosion **1,** 95 (1945) June.

In order to study the effectiveness of zinc for the cathodic protection of iron and steel under various soil conditions, zinc-iron couples were buried at eight test sites in 1941. The electrical measurement data presented includes (1) the current flowing in the galvanic circuit; (2) the potential of each electrode to a copper-copper-sulfate electrode after opening all circuits for 1 hour; (3) the voltage of the couple; (4) the current required for cathodic protection of the iron rings. The couples from two sites have been removed and examined. One of these shows moderate protection and the other almost complete protection. A possible explanation for the different results at the two stations is offered.

Developing Magnesium for Cathodic Protection. PORTER HART AND YALE W. TITTERINGTON, Dow Chemical Co. Corrosion **1,** 59 (1945) June.

Magnesium theoretically has many advantages as a galvanic anode. The efficiency and life of magnesium anodes depend on composition, backfill and current density. Field installations are reported along with studies on local action corrosion of anode which indicate that with proper backfill magnesium anodes offer an economical source of current for cathodic protection.

Use of Forced Drainage Systems in Stray Current Areas. ERIC G. CARLSON, Bell Telephone Co. Corrosion **1,** 31 (1945) Mar.

Design and control of forced drainage systems, having characteristics similar to normal drainage systems are discussed. This system of control of forced drainage gives the electrolysis engineer a satisfactory method for reducing anodic exposures in areas which are difficult to correct by means of normal drainage.

Corrosion Protection for Transcontinental Cable West of Salt Lake City, Utah. T. J. MAITLAND, American Telephone & Telegraph Co. Corrosion, **1,** 47 (1945) June.

Following a study of soil conditions and consideration of both rectifiers and zinc anodes sources of current, zinc anodes were chosen for protection of this thermoplastic coated cable. The choice of zinc anodes for this service was made on the basis of (1) economy of material, (2) ease of installation, and (3), low maintenance. The expected limitations of zinc anodes are (1) requires a low resistance ground, (2) may become passive, and

(3) a comparatively well insulated covering is required.

Recent Progress in the Mitigation of Underground Corrosion. KIRK H. LOGAN, Bureau of Standards, Oil and Gas Jl. **43**, No. 36, 78-84 (1945) Jan. 13.

Paper describes briefly the progress in the mitigation of corrosion during past two years. Methods and apparatus for scientifically determining the amount of current required for cathodic protection have been developed. Field investigation shows that zinc anodes remain effective throughout their life. Tests of coatings on one-year-old pipe lines indicate that it is possible to lay coated lines with less than one holiday per mile. A new and more effective holiday detector has been developed.

GALVANIC CORROSION

Galvanic Corrosiveness of Soil Waters. H. S. PHELPS and F. KAHN, A I E E Technical Paper No. 45-60 presented at Jan., 1945, Meetings of Institute. Elec. Eng. **64**, 156 (1945) Apr.

Data are presented on the electrode-potentials and polarization characteristics of copper, lead, iron and carbon in soil waters which vary in pH from 2 to 12. The following tentative conclusions are presented:

1. Galvanic corrosiveness on lead, copper and iron appears generally more severe for soil waters of low pH than for those of high pH.

2. Indications are that the static potentials of lead and iron are practically constant in soil electrolytes of pH up to approximately 10, as pH is increased above 10, lead becomes more negative and iron more positive. The potential of copper becomes more negative in substantially straight-line relation with increasing pH. Carbon potentials appear to be practically independent of pH.

3. For electrodes of lead, copper, iron and carbon in soil waters, the relation of degree of polarization to pH of electrolyte seems to show definite trends.

Cathodic Corrosion of Cable Sheaths. HERMAN HALPERIN. Trans. Electrochem. Soc. **87**, 14 pp. preprint (1945).

Serious cathodic corrosion of cable sheaths has occurred with increasing frequency in an underground power cable system. Most troubles occurred where the conduits containing the cables are close to electric street railway track switches. Rock salt is used on the switches during the winter months to prevent freezing. Cable-sheath corrosion near the switches is caused by NaOH produced by decomposition of the NaCl by electrolysis with the sheaths negative to earth, especially with relatively high negative voltages. Various methods have been used to retard the growing tendency for troubles due to cathodic corrosion. Also, special tests of potentials and leakage currents from a slug pulled through an idle duct were developed and used, in general with success, to detect underground

locations having corrosive conditions, in order that steps could be taken to avoid service failures of cable. Further steps to reduce these troubles are: reduction of voltage drops on railway return systems and development of an economical substitute for NaCl for use on track switches. C. A. **39**, 895 (1945) Mar. 10.

Study of A-C Sheath Currents and Their Effect on Lead-Cable Sheath Corrosion. C. M. SHERER and K. J. GRANBOLES, A I E E Technical Paper No. 45-61, presented at the Jan. meeting of the Institute.

Field observations were made in two cases of lead cable sheath corrosion which indicated a partial rectification in the alternating current flowing from the cable sheath to ground. The rectification phenomenon was studied in laboratory experiments with lead-copper cells. Tabulations of data are presented, together with curves illustrating the rectification phenomenon on new and aged cells. The experiments and observations indicate that initially the corrosive action was accelerated by the alternating currents which were induced in the cable sheath by the load current.

Corrosion Ratings of Metals. Westinghouse Electric & Mfg. Co. Steel, **116**, No. 4, 98-104 (1945), Jan.

Recommended corrosion ratings for various commercial metals and alloys are tabulated for rural, urban and marine atmospheres and for five industrial atmospheres, including ammonia, hydrogen sulphite, hydrogen chloride, sulphur dioxide and chlorine. Provisional sea water ratings are given for aluminum and magnesium alloys, copper and copper alloys and alloys of iron, nickel and chromium. A brief discussion of galvanic corrosion is included with a special arrangement of the electrochemical series. The tabulations are presented as guides in the selection of metals for use under various corrosive conditions. Similar information is published by the Westinghouse Electric and Mfg. Co. under "Corrosion Ratings of Metals and Alloys" in the Westinghouse Engineer—**5**, No. 2, 36-59 (1945). Mar.

REFINERY CORROSION

Control of Refinery Corrosion Dependent Upon an Eternally Vigilant Program. Oil Gas J. **43**, No. 47, 246 (1945) Mar. 31.

Refinery corrosion problems are summarized as follows: 1, corrosion in topping units due to acids released from crudes in distillation; 2, acid attack in the distillation of acid-treated distillate stocks; 3, acid attack from breakdown of organic sulfur compounds and alkaline earth salts in the charge to thermal-cracking units; 4, H_2S attack in gas-treating and stabilization units; 5, direct chemical attack from substances used in treating and processing units; 6, pitting of lines and equipment from salts and oxygen contained in water in cooling water systems; 7, atmospheric fume and spray corrosion. Methods of combatting corrosion and the manner of

application of each method are discussed in this paper. Selection of proper metal resistant to the particular corrosion encountered, i. e. 7-14% Cr. alloys for tubes in cracking furnaces running sour crudes, 70%—30% Ni tubes for water corrosion, 4-6% Cr. for H_2S corrosion on oil side (no effect on water side). Protective coatings and liners, i. e.—(a) 12-14% Cr. steel liners for fractionating towers, (b) galvanized plate for roofs handling sour distillate, (c) brass-clad tube sheets superior to brass, (d) Hastelloy weld lined plug valves for HCl service, (e) thermo-setting (phenolic resins) coatings on steel and admiralty tube bundles, (f) synthetic rubber coatings on steel tube sheets and as pipe linings, (g) Neoprene cement used in West Texas sour crude tank, (h) gunnite liners for periods of short service. (3) Chemical neutralization and inhibitors in hydrocarbon phase-ammonia, caustic and quachrom glucosate used. (4) Chemical neutralization and protective film formation on cooling water systems. (a) sodium hexametaphosphate,, NaOH, Na_2, Cr_2O_7 and glucosates. (b) desalting. (5) Electrical methods. Cathodic protection. (6) Mechanical. (a) flushing media, (b) mechanical and coalescent type water separators and (c) mechanical deaeration.

The Fractionation of Hydrofluoric Acid and Its Significance in H. F. Alkylation. RANDAL MAASS, Ref. Engr., General Petroleum Corp. of California. Petr. Eng. **16,** 194 (1945) Feb.

Corrosion in acid preheater has been serious problem. In general, the petroleum industry has alleviated this trouble somewhat by supplying heat through a forced circulation type reboiler in which the tower bottoms are pumped through an exchanger and returned to the tower. Acid regenerator tower also suffers severe corrosion. New monel-lined tower, equipped with monel trays and caps has been installed. In addition, the bottom cycle pumps were provided with monel runners and the valves (globe) in the hot oil system were provided with monel trim. Monel tower has not been inspected but monel in trim and pump runners has given excellent service. Corrosion in condensing system of debutanizer which followed immediately after the bauxite towers is quite severe at times as a result of hydrolysis of SiF_4 producing HF. This corrosion was reduced by adding quick lime to the bauxite tower packing, by neutralization of overhead products with caustic and by running acid of higher purity so that less alkyl-fluorides were formed and thus less acid.

Mechanical Operation of HF Alkylation Units. R. A. FINDLAY, Phillips Petroleum Co., Bartlesville, Okla. Natl. Petr. News. **37,** R-326 (1945) May 2.

The hydrofluoric acid alkylation plants constructed in the wartime aviation gasoline program were designed with extreme attention to the mechanical problems involved in handling

HF on a large scale. Equipment to handle acid was carefully segregated in concrete basins, all of which drained to a neutralizing pit containing lime water. The following special factors in design are of extreme importance: (1) If steel equipment is used, clearances must be greater than normal because of sticky nature of iron fluoride and its tendency to form—(monel does not show this tendency). (2) Use of bolts in contact with HF is to be avoided. K monel is suggested as more satisfactory than steel. (3) Development of specially designed packing glands. Properly designed and operated Duraseals on Stratco contactors have been very satisfactory. Plug valves have not proven too satisfactory. Plug valves have so little clearance that steel sticks very badly. Combination of Stellited plugs and monel-coated bodies has so far given fairly satisfactory service. Plug valve failures involves cracking of plug, breaking of cover plate stud bolts, equalizer ring failure and inner diaphragm failure. Monel trim gate and globe valves have proven quite satisfactory. Corrosion in general has not been severe in HF alkylation units, except where dilute HF is encountered as in reboiler section of the acid rerun column. Monel linings have not been too satisfactory because of difficulty of installing without minute cracks which encourage accelerated corrosion. Monel clad steel is considered more satisfactory. Special corrosion problems have developed in floating head type condensers, steam preheater tubes, and steam preheater tube sheets. Floating heads are to be avoided in preference to V-tube construction. Changing acid flow in preheaters from shell side to downward flow through tubes in preheaters has been beneficial. Little difficulty has been experienced with operation of instruments in HF service. Assuming satisfactory design and care in operation, an HF alkylation unit is one of the safest and most troubleless of refinery units.

Stainless Steels Minimize Corrosion in Processing Sour Crude Oils. R. B. TUTTLE, Oil and Gas J. **44**, No. 6, 104 (1945) June 16.

Recent inspection of topping-vacuum-cracking plant is described. Carbon steel piping and 4-6 Cr. valves handling hot light and heavy gas oil showed rapid failure with the heavy gas oil service being more severe. In general corrosion of processing equipment was evident from atmospheric fractionator on through cracking sections with maximum loss occurring in heavy gas oil section of cracker. During shutdown bottom section of atmospheric bubble tower was lined with gannister, carbon steel hot gas oil line was replaced with 4-6 Cr. and stainless steel bubble decks were installed in pressure distillate tower.

Procedure for Application of Stainless-Steel Strip Lines to Refinery Vessels in the Field. K. E. LUGER, K. E. Luger Co., Houston, Texas. Petr. Ref. **24**, 173 (1945) May.

Procedure for lining vessels is presented in detail.

The Role of the Straight Chromium Stainless Steels for Vessel Linings in the Refinery Field. W. J. JACKEL, A. O. Smith Corp. Corrosion **1**, 83 (1945) June.

The role of straight chromium steels as they have been employed in refinery vessel linings is discussed. The 12%

chromium steels have found wide usage. The higher chromium steels are subject to embrittlement after exposure at 750°-950° F. Addition of 0.25% aluminum to these steels has resulted in restriction of air-hardening characteristics.

INSPECTION

Penetron Quickly Determines Steel Thickness — Also, Without Connection to Liquids, Finds Levels and Densities. Oil and Gas J. **44**, No. 8, 106 (1945) June 30.

Penetron is an instrument for determining wall thickness without mechanical measuring, calipering, drilling, or feeling operations. It utilizes the principle of bombarding matter with penetrating radiations from radium and measuring the intensity of "back scattered" or returned rays. The radiation is picked up by a detector and translated into a direct current reading on an indicating micro-ammeter. Readings obtained on the micro-ammeter are directly indicative of wall thickness and are connected to wall thickness by means of calibration charts. Accuracy is on order of 3%. The penetron measures the average thickness over an area of approximately 1 sq. in. Therefore, it cannot be used for detecting pin holes.

By proper instrumentation the method may be adopted to control as well as to locate liquid levels. Similarly density measurements can be made and operational applications developed to control blending operations.

Caliper for Inspecting Tubing Has Four Distinct Advantages. Oil & Gas J. **44**, No. 7, 107 (1945) June 23.

The alternating current caliper pictured appears to be practical because (1) the measuring head is light and sturdy, (2) indications are rapid, (3) it provides a continuous indication of the inside diameter, and (4) there is no switch or other device which might cause a hazardous electric spark.

PROTECTIVE TREATMENT OF METALS

Shot Peening and the Fatigue of Metals. H. F. Moore, Univ. of Ill., American Foundry Equipment Co., Mishawaka, Ind., U. S. A. (1944).

Shot peening is a term used to denote the process of subjecting the surface of a metal machine part or structural member to a rain of metallic shot driven against the surface by the momentum of the shot as it is released from the rotating blades of a wheel, or by an air blast. Repeated stress such as improper shot peening may bring about the following undesirable conditions: 1, excessive elastic deformation; 2, elastic buckling; 3, plastic deformation; 4, creep; 5, fracture. Shot peening increases the fatigue strength of the metal in two ways: 1, tensile strength of the skin is increased; and 2, the effective tensile stress set up by a given load applied stress is diminished by the compressive stress set up in the skin by shot peening. It is a form of cold working. Shot peening can be applied to irregular shapes, in which heat-treating processes might cause excessive distortion, and in which rolling or drawing processes are not feasible. Shot peening can be applied to finished parts, such as springs and gear teeth. It can be used as a surface

finish in place of polishing, with actual gain in fatigue strength and reduction in production costs.

Machinery, **51**, 170 (1945) Apr. indicates widening field for application of shot peening and describes a special machine for carrying out process on large scale.

SURFACE TREATMENT

The Protection of Split-ring Connectors Against Corrosion. B. WHITINGTON. J. Council Sci. Ind. Research, **17**, 162-6 (1944).

The relative protective values of 16 different anti-corrosive treatments for split-ring connectors were tested over a period of 5 years. The most effective treatment was hot-dip zinc coating (galvanizing). C. A. **39**, 266 (1945) Jan. 20.

Shot for Metal Peening. OSCAR E. HARDER and JAMES T. GOW. Battelle Memorial Inst. Steel **116**, No. 14, 111 (1945) Apr. 2.

Growing interest in improving the fatigue endurance of metals and alloys by shot peening has served to focus attention on the shot used. Composition properties and micro-structures of chilled Fe, malleableized chilled Fe and special heat-treated Fe shots are given. The last has high hardness and improved resistance to fracturing. Steel shot is costly and generally not available.

Nitriding the Austenitic Steels Improves Wear Resistance. I. A. BINDER. Am. Machinist, **88**, 102-4 (1944).

A case depth of 0.004-0.006 in. is obtained when a Cr 13-15, Ni 13-15, W austenitic steel 1½-3% is nitrided for 50 hrs. at 1000° F. Successful production depends upon careful control of size prior to nitriding so that the final grinding operation will not remove the case. Details of the process as applied to aircraft engine valves are given. C. A. **39**, 683 (1945) Feb. 20.

Protective Treatments for Magnesium Alloys. JEROME L. BLEIWEIS and A. J. FUSCO. Materials and Method Manual No. 3. Metals and Alloys, **21**, No. 2, 417-434 (1945) Feb.

The Manual presents a comprehensive review of virtually all of the protective surface treatments developed to date for magnesium alloys. Data are presented on the methods and materials used in each process. Detailed information is given on the techniques for the application of the more common chemical surface treatments and on the plating and painting of these alloys. The general subject of metal corrosion and its control are discussed in the opening section of the Manual.

Electropolishing of Steel for Microscopic Examination. S. R. PRANCE, Chief Metallurgist Inland Mfg. Div., Gen. Motors Corp., Dayton, Ohio.

Provides excellent means of polishing without undue time and effort.

Samples are prepared by facing on 80-100 girt grinding wheels and followed by short-time preparation

on No. 1 metallographic paper. Sample is then treated in electrolytic polishing bath for 1½ to 4 min. depending on size.

Bath, solutions, operation and proper precautions, are described.

Rust Prevention. G. W. PRESSELL, E. F. Houghton and Co. Industry and Power, **48**, No. 3, 70-72, 165-7, (1945) Mar.

When the nation's major war production effort is over and industries begin to convert from war to peace, a gigantic task of rust prevention will arise. The government has taken steps to standardize on protection of idle machines for shipment, stand-by, and extended storage. Causes of corrosion with emphasis on surface conditions which cause corrosion or prevent the preventive measures from being effective are discussed. Cleaning by mechanical and chemical methods is discussed. Special corrosion preventive compounds are divided into four general groups for discussion: grease type, oil type, solvent type, and "strippable" plastic type.

Practical Information About Cleaning and Cleaners. A. J. HEREFORD, International Engineering Corp., Atlanta, Ga. Southern Power and Industry, **63**, No. 4, 112 (1945) Apr.

Metallurgically, clean means the absence of any materials on the surface which will stimulate corrosion and interfere with application. Nondrying oils and greases may be removed by saponification, emulsification and/or solvents (liquid or vapor). Cleaning operations may be carried out by soaking or spraying. Soaking methods can be accelerated by electrolyzing solution. All cleaning operations are aided by agitation and usually by heat.

PIPELINE CORROSION

Ruptured Pipe Lines—Preventive Maintenance and Corrective Procedures. F. B. NEPTUNE, Phillips Petroleum Pipe Line. Oil and Gas J. **44**, No. 8, 120 (1945) June 30. Also National Petr. News, **37**, No. 27, R561 (1945) July 4.

Phillips coats all cross-country trunk products lines, using either asphalt-mastic or coal-tar enamel with bonded wrap. Treatment of gathering lines depends on soil conditions. Methodical inspection and repair practices are developed and detailed records are maintained. Internal corrosion is fought by excluding as much air and water from line as possible, adding reducing or passivating chemicals such as sodium sulfite, sodium chromate, sodium nitrite and mercaptobenzothiazole. Phillips developed and is using mercaptobenzothiazole (Rokon). The company has been able to discontinue scrapers in Rokon treated lines. Future development indicates the introduction of plastic coated pipe for protection against both internal and external corrosion.

Economics of Mitigation of External Corrosion on Underground Pipe Lines. J. CAMPBELL STIRLING, Stanolind Pipe Co. Corrosion **1**, 17 (1945) Mar.

There are in the U. S. approximately 333,000 miles of pipeline carrying

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petroleum products and which cost about $3,200,000,000. The annual loss due to corrosion is estimated to be $50,000,000. Case histories are presented to show the benefits of properly applied coatings and cathodic protection.

Electrolytic Corrosion Methods of Evaluating Insulating Materials Used in Tropical Service. B. H. THOMPSON and K. N. MATHES. General Electric Company, Electrical Engineering **64,** Trans. 295 (1945) June.

The selection of insulating materials to guard against electrolytic corrosion has become increasingly important as the use of electrical devices in the tropics has increased. Moisture conditions in the tropics are described, and means for producing such conditions in the laboratory are considered. The visual, corrosion-current, and water extract conductivity methods for studying electrolytic corrosion are described. Typical results for a number of different materials are given.

Used Cement-Lined Pipe. W. L. NELSON. Oil & Gas J. **44,** No. 10, 116 (1945) July 14.

The modern pipe developed for use in the oil industry has such a high strength and such thorough bonding of the cement to pipe that no special precautions are required in handling it. Pipe fittings are also available.

Dimensions and weights and costs of cement-lined pipe are given.

CHEMICAL CORROSION

Corrosion by Phenol at High Temperatures. A. WACHTER and N. STILLMAN, Shell Development Co., Electrochem. Soc. Trans. **87** (preprint 11) : 115 (1945) April.

Corrosion of carbon steel increased very rapidly above 200° C. Addition of 0.2% to 0.6% water to anhydrous phenol decreased corrosion rate while further addition of water greatly increased it. Addition of sulfur compounds caused an increase in corrosion rate. Comparative tests on steel, 12 Cr. steel, 18/8 stainless steel, 18/8 Mo. stainless steel, Durimet stainless steel, 24/20 stainless steel, nickel and aluminum 2-S showed 12 Cr. steel to be somewhat superior to low carbon steel. All stainless steels showed very low rates. Nickel was attacked in used plant phenol and aluminum was severely attacked.

Ceramic Linings for Acid Tanks. RICHARD NEUHAUS, Products Corporation. Petr. Refr. **24,** 194 (1945) May.

Type of construction outlined is suited to all acids, with variations in material. Suggested materials for handling surfuric, hydrochloric and nitric acids include:

Membrane: Rubberized asphaltic compounds or properly selected synthetic rubber for all four acids; rubber for all except nitric or lead for sulfuric.

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Cement: Sulfur-base cements for all four acids up to 200° F. resinous cements for sulfuric, hydrochloric and nitric acids up to 275° F; silica cements for sulfuric, hydrochloric and nitric acids of not less than 5% strength and up to several hundred degrees temp.

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CORROSION TESTING

An Apparatus for Measuring Corrosion. MORRIS COHEN, National Research Council, Canada. Electrochem. Soc. Trans. (Preprint 19) **87**, 221 (1945) April.

A multiple unit total immersion test apparatus is presented which provides circulation of solution without exposure of sample to air. Good reproducibility is shown by results of the effect of three different waters on the corrosion of steel.

Laboratory Corrosion Tests. R. M. BURNS, Bell Telephone Co. Ind. Eng. Chem. Anal. Ed. **17**, 299 (1945) May.

It is preferable to carry out corrosion studies under nearly natural conditions and to use sensitive measuring techniques to determine rate of reaction rather than to depend upon highly accelerated tests to furnish the larger effects which can be detected by less precise methods of measurement. Methods of measurement, preparation of test specimens, and description of tests and testing facilities are discussed. The tests discussed are total immersion test, atmospheric test, salt spray test, and electrochemical techniques.

Laboratory Tests to Predict the Performance of Metals Under Service Conditions. D. W. SAWYER and R. B. MEARS. Aluminum Research Lab. Ind. Eng. Chem. Anal. Ed. **17**, (1945) Jan.

Data presented to emphasize the fact that to predict the performance of metals under service conditions, a laboratory test must give results that correlate directly with service results. The most certain method of designing a suitable laboratory test is to simulate the conditions of service as closely as possible. Attempts to accelerate the laboratory test by intensifying one of the factors encountered in service is often misleading. Examples are cited to show the value of electrical measurements for predicting the feasibility of using cathodic protection for aluminum chemical equipment.

WATER CORROSION

Scale-Forming and Corrosive Tendencies of Water Predicted by Rapid Methods. JOE R. WRIGHT, Wright Petroleum Laboratories, Tulsa. Oil and Gas J. **44**, No. 7, 99 (1945) June 23.

A history of the development of the terms saturation and stability indexes is presented with full explanation of Langelier's equation for calculating saturation index and Hirsch's scale diagram for determining stability index of water. The corrosiveness or scale-forming tendencies of water can be predicted from these calculations. Limitations are that the equilibrium values of $Mg(OH)_2$ in lime-soda ash softened water is not considered. Also the equations do not take the dissolved oxygen content into consideration when predicting the corrosiveness of water.

Stability Index Judges Cooling Water. JOE R. WRIGHT, Wright Petroleum Laboratories, Tulsa. Oil and Gas J. **44**, No. 10, 112 (1945) July 14.

Application of stability-index calculations allows accurate predictions of what may be expected, provided a proper analysis is available and service temperatures are known. Specific examples are given where stability index predicts the performance of cool-

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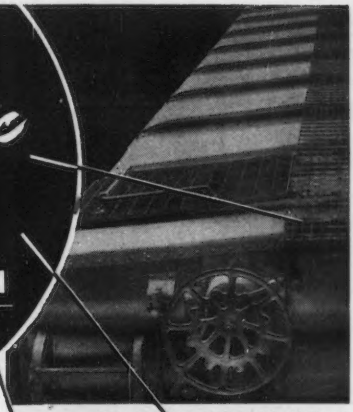

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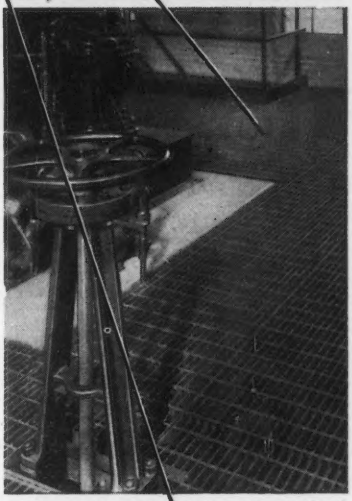

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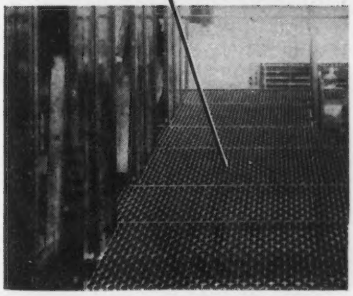

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ing waters and points to remedial treatment for scale and corrosion. Stability index values go up with temperatures so that scale forming tendency increases. Quality of water can be raised by choice of pH and operating temperature.

MARINE CORROSION

Relationships Between Corrosion and Fouling of Copper-Nickel Alloys in Sea Water. F. L. LaQue, International Nickel Co. and Wm. F. Clapp, Clapp Laboratories, Electrochem Soc. Trans. (Preprint 15) **87**, 165 (1945) Apr.

This article is a report of one series of investigations (among a large number) carried out at Kure Beach, N. C.

The following information was obtained on the relationship between fouling and corrosion. (1) The copper alloy prevented fouling if copper was released at a rate greater than 4.5 to 7 mg/dm²/day. (2) The alloy could contain no more than 30 to 40% nickel and prevent fouling. (3) The fouling organisms accelerated corrosion especially after death. (4) Alloys that did not foul showed decreases in corrosion rates as the period of exposure was prolonged. (5) Alloys that fouled showed increases in corrosion rates when fouling developed as the period of exposure was prolonged. (6) The results suggested that the sloughing off of solid corrosion products must be considered, along with toxicity, as a major factor in determining the fouling characteristics of metals and alloys in sea water.

Corrosion of Steels in Marine Atmospheres and in Sea Water. C. P. Larrabee, Research Laboratory, Carnegie-Illinois Steel Corporation. Marine Engineering **L**, 167 (1945) June.

The sulfur dioxide contaminated atmosphere at industrial locations, especially where the contamination was greatest, caused more corrosion than the sea salt deposited on specimens at any marine site.

Low alloy, high strength steels, with superior resistance in industrial atmospheres are also more resistant in marine atmospheres, but to varyi - extents.

Slight rusting usually mars the appearance of the lower grades of stainless steel in sea coast atmospheres, but in most cases the attack is only superficial.

Zinc coatings offer considerable promise.

The problem of corrosion in sea water is complicated by presence of marine organisms. It appears that addition of about 3% molybdenum to 18-8 steels reduces pitting. Stainless steels perform better at velocities greater than 5 ft/sec. Stainless steel impellers have been found particularly satisfactory in pumps handling polluted harbor waters, especially with hydrogen sulfide present.

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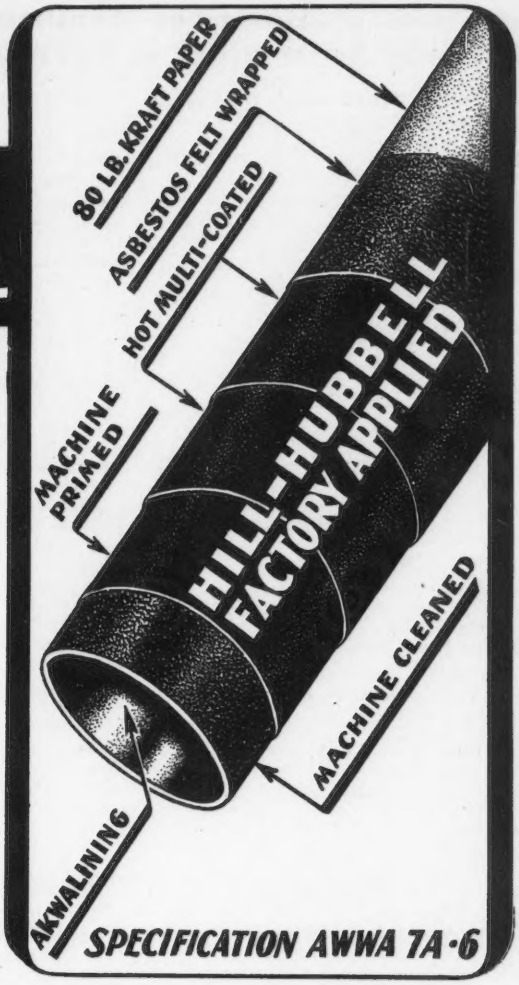

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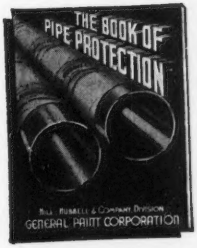

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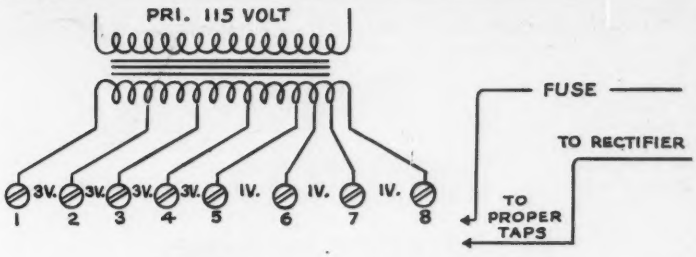

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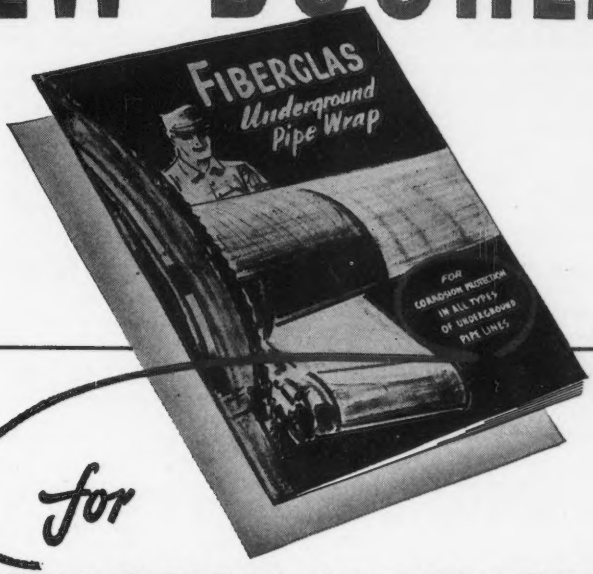

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